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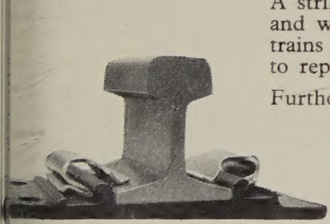
(English Edition)



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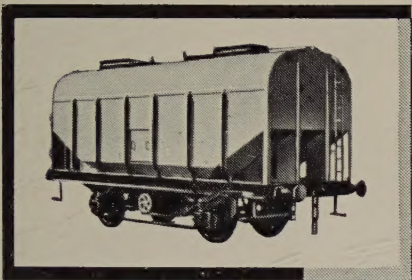

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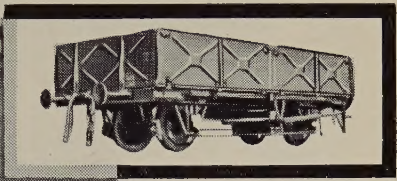

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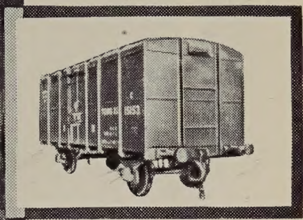

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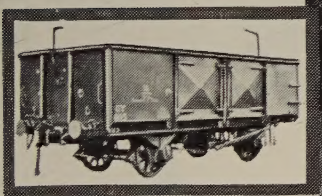

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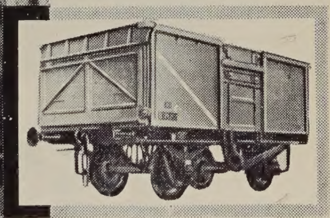

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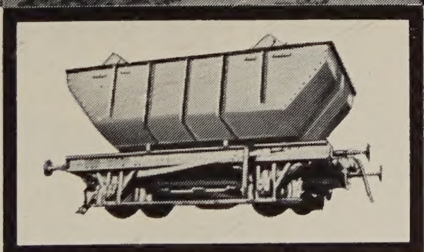

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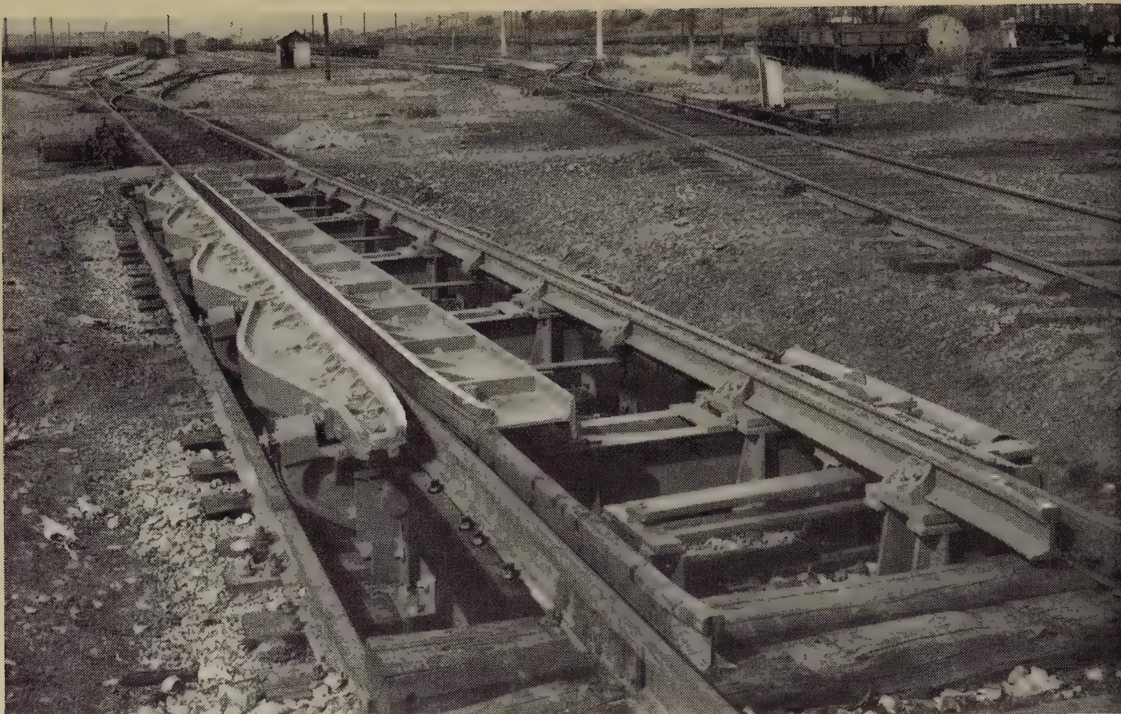

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BULLETIN
OF THE
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ASSOCIATION
(ENGLISH EDITION)

[625 .14 (01 & 625 .2 (01]

Contact between wheel and rail.

Variation of contact area and maximum shear with the curvatures of the contacting bodies,

by C. Storey,

Mathematician, British Railways Research Department.

SUMMARY

An investigation has been made into the variation of contact area and maximum shear stress with the four radii of curvature of the two bodies in contact. Results are given which cover the practical range of variation of these curvatures. It is concluded that curvature of the rail due to bending and variation of the angle between the wheel and the rail are unimportant. The results also strengthen the intuitive view that the effect of wear is generally to reduce the stresses.

INTRODUCTION

When the Hertzian theory of contact is applied to the contact between wheel and rail, the usual practice is to consider either a cylinder on a plane or a pair of right circular cylinders with their axes perpendicular. These two cases correspond to a new wheel on a rail worn flat and a new wheel on a rail with a specific head radius — neither of which conditions are realised in practice. In general, wheels are worn hollow quite quickly after going into service either new or freshly turned and, because of the resilience of the track, rails will be bent longitudinally by the load. Further, the angle between the axes of wheel and rail will seldom be 90° but will vary by a small amount from this.

It is the purpose of the present work to examine the dependence of contact area, and hence stresses, on all four principal radii of the contacting bodies and on the angle between their principal sections. The range of variation of the curvatures and inclination of the axes will be such that a practical discussion of the contact of railway wheels and rails can be given for static loads. A brief summary of the relevant theory precedes the results of the calculations.

THEORY

Suppose two bodies to be in contact at a single point, which is supposed not

to be a singular point of either body. Take this point as origin of a system of rectangular co-ordinates, the xy-plane being the common tangent plane to the two bodies at the point of contact and the z-axis the common normal. Denote the principal curvatures of the bodies by ρ_{11}, ρ_{12}, ρ_{21}, ρ_{22}, their signs being positive when the corresponding centres of curvature lie within the bodies. Then if the x and y axes lie in the principal sections of the upper body (denoted by left-hand suffix 1) the equation of the surface of this body in the neighbourhood of the point of contact may be written :

$$2z_1 = \rho_{11}x_1^2 + \rho_{12}y_1^2 \qquad \ldots . (1) \qquad \text{(see ref. 1)}$$

Hence, if instead of lying in the principal section Ox is inclined at an angle ω' to it, (1) becomes :

$$2z_1 = \rho_{11}(x \cos \omega' + y \sin \omega')^2 + \rho_{12}(y \cos \omega' - x \sin \omega')^2 \qquad \ldots . (2)$$

If, now, the planes of ρ_{11} and ρ_{21} are inclined at an angle ω, the x, y axes are inclined at $(\omega' - \omega)$ to the principal sections of the second body, and hence the surface of this body may be written :

$$\begin{aligned} 2z_2 = &- \rho_{21}\{x \cos(\omega' - \omega) + y \sin(\omega' - \omega)\}^2 \\ &- \rho_{22}\{y \cos(\omega' - \omega) - x \sin(\omega' - \omega)\}^2 \end{aligned} \qquad \ldots . (3)$$

The distance apart of corresponding points on the two surfaces will be given by $z_1 - z_2$. Let this be put equal to $Ax^2 + By^2$: then by equating coefficients of x^2, y^2 and xy from the expression for $z_1 - z_2$ obtained from equations (2) and (3) to A, B and 0 respectively, it is seen that :

$$2(A + B) = \rho_{11} + \rho_{12} + \rho_{21} + \rho_{22}$$

$$2(A - B) = \sqrt{(\rho_{11} - \rho_{12})^2 + 2(\rho_{11} - \rho_{12})(\rho_{21} - \rho_{22}) \cos 2\omega + (\rho_{21} + \rho_{22})^2}$$

$$\text{and } \tan 2\omega' = \frac{(\rho_{21} - \rho_{22}) \sin 2\omega}{\rho_{11} - \rho_{12} + (\rho_{21} - \rho_{22}) \cos 2\omega}$$

When $\omega = 90°$ these become :

$$2(A + B) = \rho_{11} + \rho_{12} + \rho_{21} + \rho_{22}$$

$$\begin{aligned} 2(A - B) &= \sqrt{(\rho_{11} - \rho_{12})^2 - 2(\rho_{11} - \rho_{12})(\rho_{21} - \rho_{22}) + (\rho_{21} + \rho_{22})^2} \\ &= \rho_{11} - \rho_{12} - \rho_{21} + \rho_{22} \end{aligned}$$

and $\qquad \omega' = 0°$

Hertz in his original paper of 1881 (see 2) gives the axes of the ellipse of contact in terms of an auxiliary angle τ as follows :

$$a = \mu \, K/\sqrt[3]{\rho_{11} + \rho_{12} + \rho_{21} + \rho_{22}} \qquad \text{(major axis)}$$

$$b = \upsilon \, K/\sqrt[3]{\rho_{11} + \rho_{12} + \rho_{21} + \rho_{22}} \qquad \text{(minor axis)}$$

where K is a constant (*) depending on the elastic properties of the bodies, and μ and υ are functions of τ. The angle τ is given by :

$$\cos \tau = \frac{B - A}{A + B}$$

and μ and υ are shown as functions of τ in figure 1 (*b*).

The stress we are most interested in is the maximum shear stress, since at this stage we are considering the maximum shear criterion for strength. This implies that stresses above half the ultimate tensile strength of the material will cause failure. Whether, in fact, this is a satisfactory criterion for the complicated phenomenon of a wheel rolling on a rail is a debatable point, since little is known about the effects of factors such as work hardening and, more generally, the mechanism of fatigue due to highly localised internal shearing stresses. It is shown in a paper by H.R. THOMAS and V.A. HOERSCH (see ref. 3) that the maximum shear stress occurs on the *z*-axis at a small distance below the surface. The magnitude of this stress and its position on the *z*-axis depends on the ratio $k = b/a$. Since a, the semi-major axis of the pressure ellipse, has already been calculated, the maximum shear is most easily calculated in the following manner. The graph of fig. 1 (*c*)

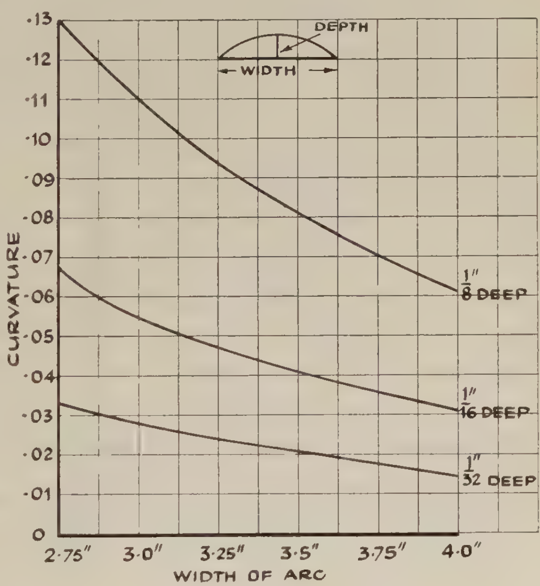


Fig. 1 (*a*).

DEPENDENCE OF CURVATURE ON DEPTH AND WIDTH OF ARC

(*) $K = \left\{\frac{3}{2} P \left(\frac{1 - \sigma_1^2}{E_1} + \frac{1 - \sigma_2^2}{E_2}\right)\right\}^{1/3}$

where P is the load and E and σ are Young's modulus and Poisson's ratio for the materials.

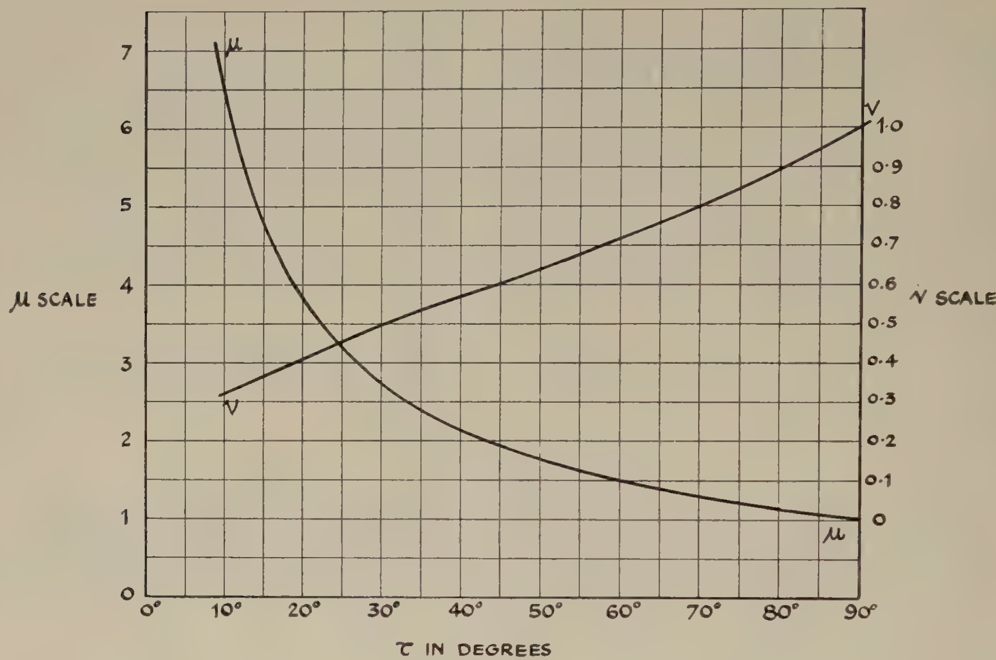
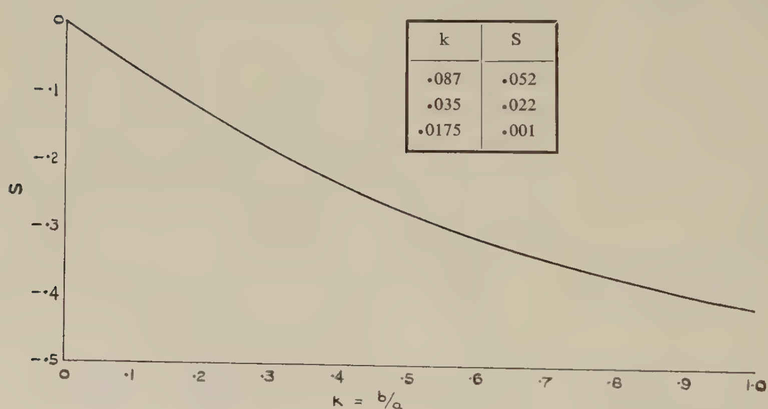


Fig. 1 (*b*).

μ AND ν AS FUNCTIONS OF τ



k	S
·087	·052
·035	·022
·0175	·001

Fig. 1 (*c*).

DEPENDENCE OF MAXIMUM
SHEAR ON $k = b/a$

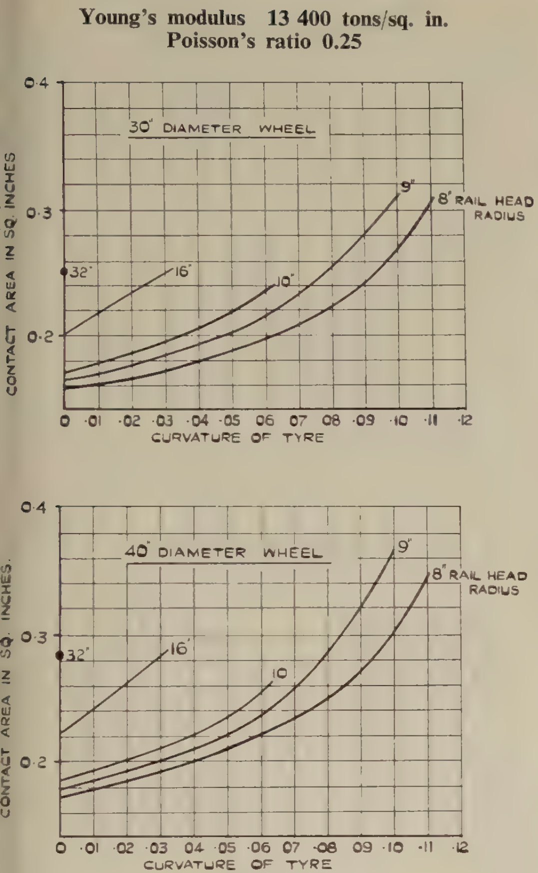


Fig. 2.
DEPENDENCE OF CONTACT AREA ON TYRE CURVATURE

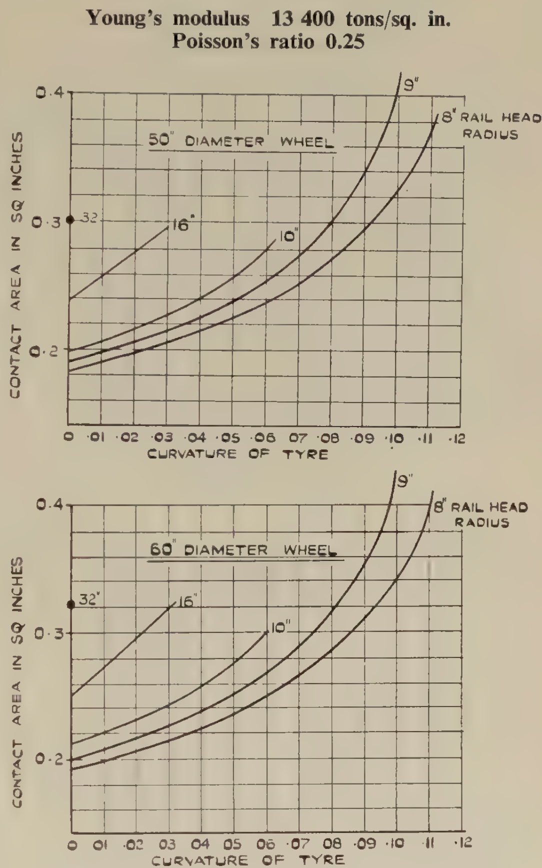


Fig. 3.
DEPENDENCE OF CONTACT AREA ON TYRE CURVATURE

[extended from (3)] is used to obtain a quantity S corresponding to the ratio k under consideration and then S is multiplied by 4/15 [Ea (A + B)] to give the required shear. In this last expression E is Young's modulus for the material of the bodies (assumed the same for both). It might be remarked here that we are assuming the bodies isotropic, which need not be at all true for rolled rails or shrunk fit tyres.

RESULTS

We take $1/\rho_{11}$ as the wheel radius, $1/\rho_{12}$ as the radius of the tyre (assumed a circular arc), $1/\rho_{21}$ as the radius of the rail head and ρ_{22} as the longitudinal curvature of the rail due to bending. The ranges of variation are as follows :

Wheel diameter (ρ_{11}) :

30″, 40″, ... 90″

Young's modulus 13 400 tons/sq. in.
Poisson's ratio 0.25

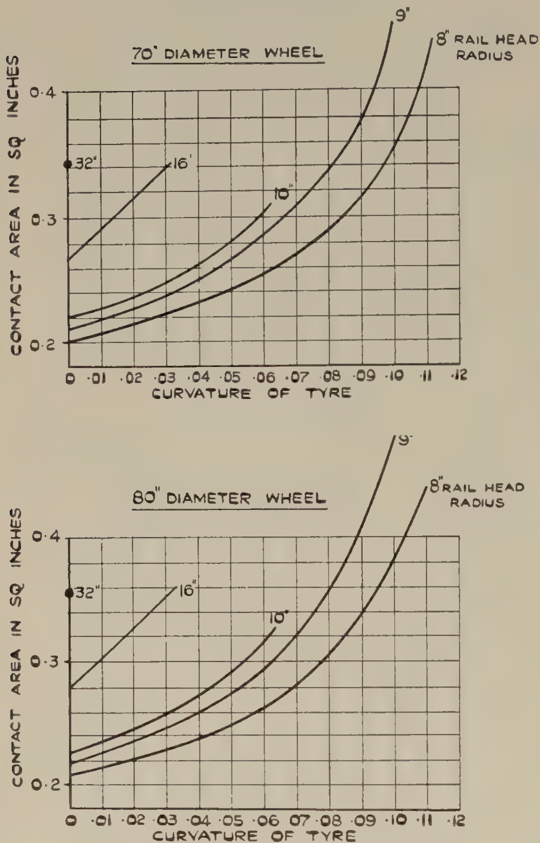


Fig. 4.

DEPENDENCE OF CONTACT AREA ON TYRE CURVATURE

ρ_{12} 0 to —·12 in 1/100ths and —·25, —·50, —1·0, —2·0, —4·0

Rail head radius (ρ_{21}) :

8″, 9″, 10″, 16″, 32″ and 4″, 2″, 1″, 1/2″, 1/4″

ρ_{22} 0, —·0005, —·0010, —·0015, —·0020

ω 70°, 80°, 85°, 87½°, 90°.

Young's modulus 13 400 tons/sq. in.
Poisson's ratio 0.25

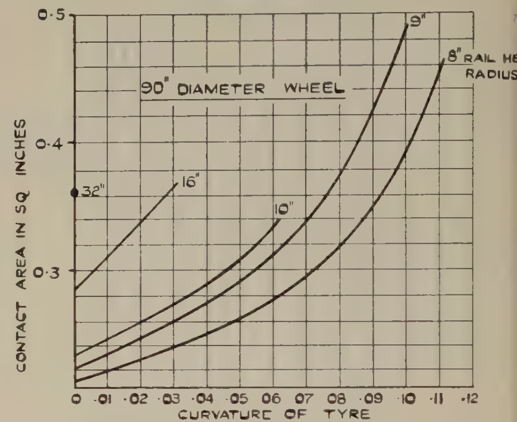


Fig. 5.

DEPENDENCE OF CONTACT AREA ON TYRE CURVATURE

The assumption of a circular arc for the profile of a worn tyre was found to be reasonable on examination of a large number of such profiles. The curvature for a given depth of arc varies with the width, and fig. 1 (*a*) shows this dependence. The average width of arc was found to vary between just under 3″ to just over 3½″. All our calculations are for a 10-ton load, but factors are given to convert to 5 and 2½ tons.

Our first conclusion is that it is quite satisfactory to neglect the curvature due to bending. Two typical examples of the effect of this curvature are shown in the table on the next page.

The bending moment under a 10-ton load placed at the mid-span of a B.R. 95 lb/yd. B.H. rail is about 75 tons inches. Hence the curvature is given by ρ_{22} = 75/EI, when EI lies between 400 000 and 500 000 tons inch^4. It is thus seen that our conclusion is justified,

TABLE 1

$\rho_{11} = \cdot 0667$, $\rho_{12} = -\cdot 1111$, $\rho_{21} = \cdot 125$		$\rho_{11} = \cdot 0222$, $\rho_{12} = -\cdot 1000$, $\rho_{21} = \cdot 1111$	
ρ_{22}	Contact area (sq. in.)	ρ_{22}	Contact area (sq. in.)
—·002	·315	—·002	·522
—·0015	·313	—·0015	·518
—·0010	·312	—·0010	·515
—·0005	·311	—·0005	·504
0	·310	0	·498

and in all that follows we have taken $\rho_{22} = 0$. The ameliorating effect of this curvature, however, is an argument against too rigid a track, and in the case of impacts where the contact loading can be very high much damage is probably averted by the track elasticity. It must also be said here, of course, that we are neglecting stress due to bending.

Now let us consider ω the angle between the planes of ρ_{11} and ρ_{21}. Table 2 gives two examples of the effect of variation of this angle :

TABLE 2

$\rho_{11} = \cdot 0667$, $\rho_{12} = 0$, $\rho_{21} = \cdot 1250$, $\rho_{22} = 0$		$\rho_{11} = \cdot 0222$, $\rho_{12} = -\cdot 03125$, $\rho_{21} = \cdot 1250$, $\rho_{22} = 0$	
ω	Contact area (sq. in.)	ω	Contact area (sq. in.)
70°	·165	70°	·264
80°	·162	80°	·245
85°	·159	85°	·242
87 ½°	·158	87 ½°	·239
90°	·157	90°	·238

Young's modulus 13 400 tons/sq. in.
Poisson's ratio 0.25

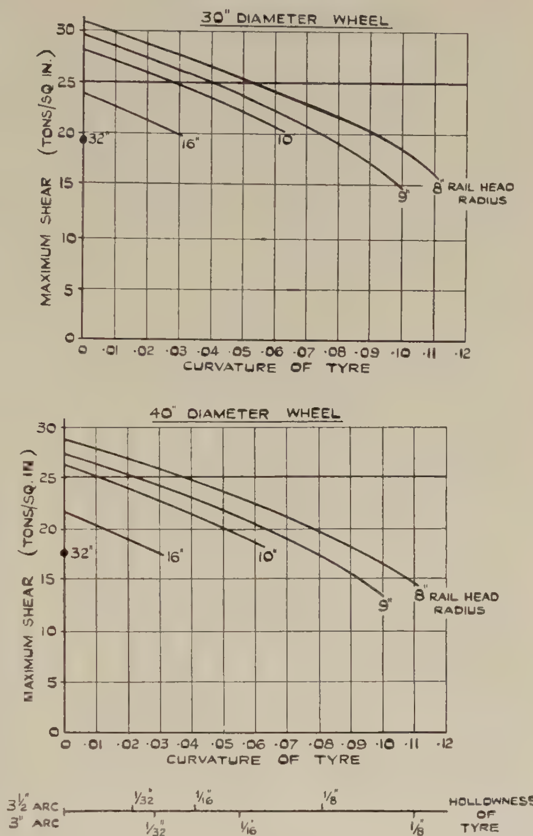


Fig. 6.
DEPENDENCE OF MAXIMUM SHEAR STRESS ON CURVATURE OF BODIES IN CONTACT

Again it is seen that this effect is negligible, since the maximum change in ω in practice must be of the order of 1°. In the sequel, therefore, we take $\omega = 90°$.

We now come to the three factors which give appreciable effects ρ_{11}, ρ_{12} and ρ_{21}. At the outset we remark that if $\rho_{12} > \rho_{21}$ there will be no contact : also if $\rho_{12} = \rho_{21}$ there will be cylindrical

Young's modulus 13 400 tons/sq. in.
Poisson's ratio 0.25

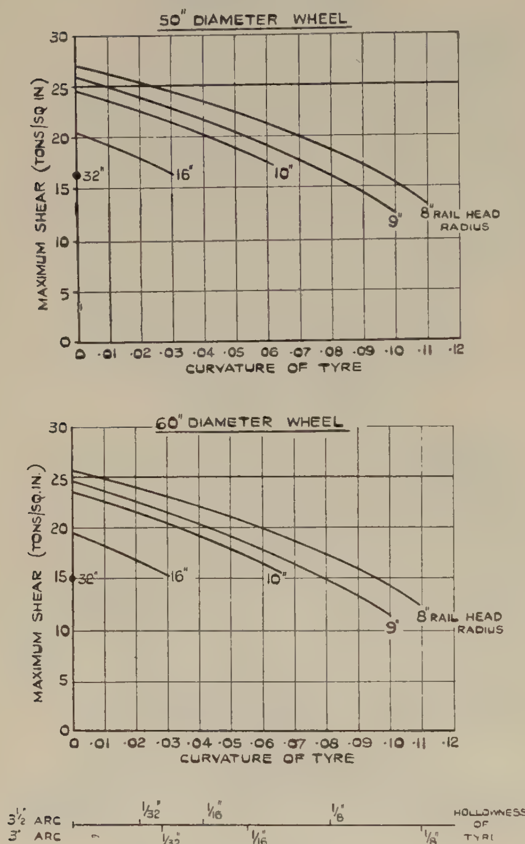


Fig. 7.

DEPENDENCE OF MAXIMUM SHEAR STRESS ON CURVATURE OF BODIES IN CONTACT

Young's modulus 13 400 tons/sq. in.
Poisson's ratio 0.25

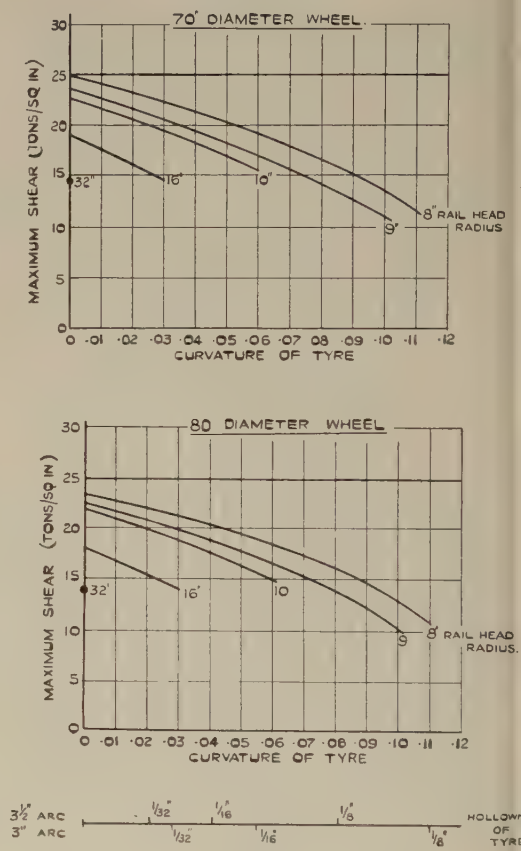


Fig. 8.

DEPENDENCE OF MAXIMUM SHEAR STRESS ON CURVATURE OF BODIES IN CONTACT

contact which we exclude from our analysis because of the indeterminate nature of the length of contact. Our results are conveniently summarised graphically, and we plot the contact area and maximum shear against curvature of tyre (ρ_{12}) giving separate curves for each rail head radius (ρ_{21}) and separate diagrams for each wheel diameter (ρ_{11}).

Figures 2 - 5 give the contact areas and figures 5 - 9 the maximum shears for contact on the crown of the rail.

On the stress diagrams a horizontal line is drawn to show 25 ton/sq. in., which is half the ultimate tensile strength for rail steel. A scale is also given showing what " hollowness " of tyre (for a 3″ and a 3 ½″ width) corresponds to ρ_{12}.

Young's modulus 13 400 tons/sq. in.
Poisson's ratio 0.25

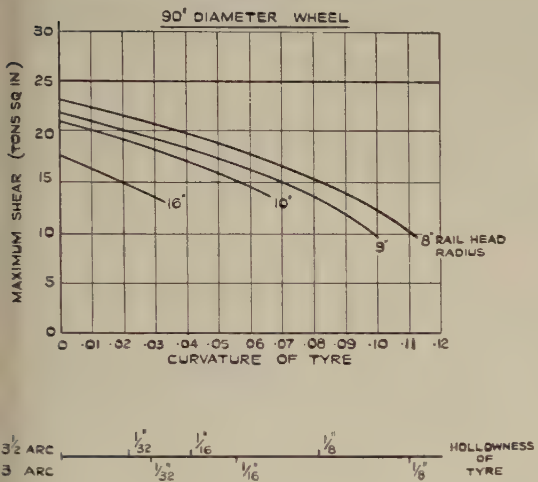


Fig. 9.
DEPENDENCE OF MAXIMUM SHEAR STRESS ON CURVATURE OF BODIES IN CONTACT

The noticeable feature is, of course, the large reduction in stress for quite moderate tyre wear. Reduction of stress also accompanies increase of wheel diameter and increase of rail head radius. Care must be taken when talking of rail wear to consider the original state of the rail head since, if the rail wears to a sharper rather than to a flatter curve, the stress is increased.

We now turn attention to the gauge corner. The rail head radius at the gauge corner can vary from 4″ down to ½″ or even less, and it may be that a relatively flat part of the tyre will come into contact with one of these smaller radii as the tyre moves across the rail head. Figure 10 shows the maximum shear for a 6″ and a 4″ rail head for the full range of wheel diameters and

Young's modulus 13 400 tons/sq. in.
Poisson's ratio 0.25

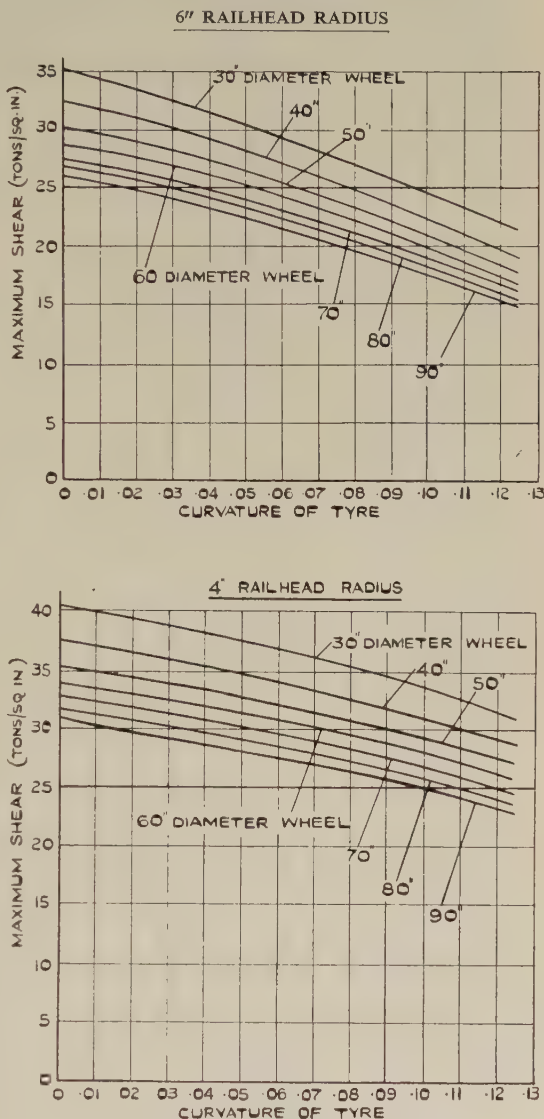


Fig. 10.

DEPENDENCE OF MAXIMUM SHEAR STRESS ON CURVATURE OF BODIES IN CONTACT

for tyre curvature (ρ_{12}) from 0 to — ·12. The stresses, as might be expected, are high. Then figure 11 gives an idea of what happens for contact of the inside corner of the rail and the throat of the tyre. In this case we get some really high stresses, e.g. up to as much as 120 ton/sq. in. With worn tyres and worn rails, however, it is possible to show that when there is contact at the inside edge of the rail the contact also extends over a considerable amount of the head, thus distributing the load.

To convert to loads of 5 tons and 2 ½ tons respectively, contact areas must be multiplied by 0·630 and 0·397; shear stresses by 0·794 and 0·630.

Young's modulus 13 400 tons/sq. in.
Poisson's ratio 0.25

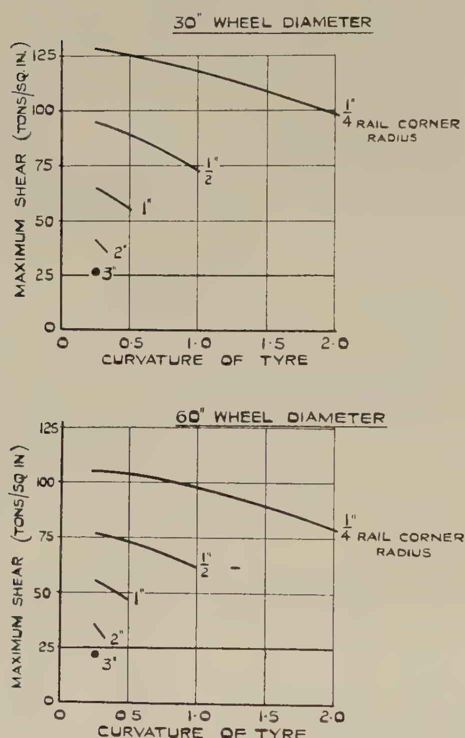


Fig. 11.
DEPENDENCE OF MAXIMUM SHEAR STRESS ON CURVATURE OF BODIES IN CONTACT

CONCLUSION

The results we have obtained strengthen the intuitive view that the effect of wear of tyres and rails is, in general, to produce a larger contact area and consequently smaller stresses. Thus the danger of assuming cylindrical wheels and flat tyres [as is done in some of the literature, see for example (4)] is made apparent.

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[656 212 .5]

Automation and its application to shunting in marshalling yards,

by Doctor-Engineer Ewald GRASSMANN.

(*Die Bundesbahn*, No. 12, June 1956).

I.

In the economically highly developed countries, manpower is becoming more and more scarce and costly. In nearly all spheres concerned with the satisfaction of human needs, modern technical development has led to mass production methods enabling an ever increasing part of mankind to share in the social products. In this way, the general standard of living has been raised to a level which may have been regarded as utopian only a few decades ago. The machines has replaced man where heavy toil called for considerable physical efforts and where the requisite degree of precision exceeded the purely mechanic potentialities of the human being. This relief from toil, achieved by intellectual effort, and the concomitant rise in the social standard of the masses exclusively due to this effort, are reflected in a marked increase in power consumption, especially as far as electric power is concerned. But this evolution has by no means come to an end, and it is with anxiety that the time is already foreseen when the sources of energy hitherto available to us will no longer permit of a further increase in energy production. Have not reputable economic experts forecast that, in Germany, power consumption will have doubled by 1965? The solution of this problem is seen in the advent of atomic power so that the development of this source of energy should be accorded the highest priority.

The mass production technique based on the use of machines and other physical devices as developed up to now, may be appropriately termed « *mechanisation* ». This technique has now found such general acceptance that there are hardly any further fields of mass production where it would still be possible to make the direct mechanisation of human toil much more effective, though this does not necessarily mean that there is no room for improvements in *quality*. But the supply of human labour will decrease as further claims for a greater share in the fruits of productivity are staked in the form of demands for even shorter working hours. At the same time, it is desired to increase the social product more and more so that more people can share it. The only solution to this problem is believed to lie in the *automation* of all working processes.

As so many other notions in modern economics, this idea comes from the United States. The American economist P. F. DUNCKER describes automation as *the use of machines for the operation of machines*. This means in practice that certain simple and often recurring thinking processes of the human brain, required for the control of machines, are entrusted to machines instead. This development is aided by modern electronics. Although the idea is not altogether new, the use of the term automation signifies that it is now intended to adopt this principle wholeheartedly and to adapt the planning of technological and similar processes to this technique to the greatest possible extent. Under present condi-

tion, it is necessary to free human labour in order to overcome man-power shortages and to divert the man-power available to other, generally more profitable tasks. Automation will not lead to mass unemployment of the kind at one time dramatised by Gerhart HAUPTMANN in *The Weavers* who were deprived of their living by the introduction of the mechanical loom.

The economic importance of modern technical evolution has been described in a particularly impressive way by the French scientist, engineer and economist Jean FOURASTIÉ in his work : *Le grand espoir du XXe siècle, Progrès technique, Progrès économique, Progrès social,* where « technical progress » is made the central conception of all economic considerations. The application of new technical and scientific discoveries to economic activities produces a continual improvement of the ratio of input and output or, to use a much-used contemporary term, an improvement in « productivity » which is beneficial to mankind at large. According to FOURASTIÉ, the key conceptions of « technical progress » and « productivity » lead to a complete re-orientation of economic activities. Systematic analysis of technical progress is the key to the comprehension of the modern world.

According to FOURASTIÉ, « technical progress » leads to an increase in the volume of production per unit of raw material or labour input. He makes a distinction between three groups of « productivity » :

1) « material productivity », measured in terms of the quantity of raw materials;

2) « economic productivity », which indicates to what extent additional capital investments will lead to an increase in production, assuming all other factors to be equal;

3) « man-power productivity ».

FOURASTIÉ then draws attention to the highly significant fact that technical progress is not equally far advanced in all branches of production. It is this difference which, according to him, is typical of the structure of modern economy, and which leads him to divide the economic world into different sectors, according to the degree of their technical progress. The « *primary* sector » comprises all branches of production with moderate technical progress such as agriculture. The « *secondary* sector » comprises all economic spheres with pronounced technical progress, largely industry. What he calls the « *tertiary* sector » includes all those economic activities where technical progress has been small, such as commerce, administration, the free professions, the occupations mainly concerned with the rendering of services, and many others.

FOURASTIÉ then puts the question whether it is « material productivity » or « man-power productivity » which is more important to mankind, and amplifies this question by examining whether technical progress should be measured in terms of one or the other. In his own opinion, man-power is the predominant factor since it has been found that « man-power productivity » directly determines the standard of living. « Investment productivity » is a special form of « material productivity » so that its effect on the standard of living need not be taken into account.

According to FOURASTIÉ, the increase in man-power productivity results in a continuous migration of man-power from the primary and secondary sectors to the tertiary sector. With the growing comprehension of the basic laws governing our contemporary economic development, all of us will gradually come to the conclusion that the increase in man-power productivity is the basis of social progress, and that social progress can therefore not be achieved without a shift and migration of man-power. It is this phenomenon which characterizes the transitory nature of contemporary civilisation. In order to arrive at a basic understanding of the problems of our time, we must regard it

as a period of transition which is unstable and therefore, of necessity, troublesome. The period in which we live marks the transition from a traditional state of equilibrium to a future and necessarily new state of equilibrium. FOURASTIÉ goes so far as to talk of the conquest of the world by the tertiary sector.

If the attempt is now made to apply FOURASTIÉ's division of all economic activites into three sectors to the railways, we find, because of their great range and geographical distribution, activities belonging to all three sectors. Administration certainly belongs to the tertiary sector. But most activities belong to the secondary sector, or at least to the primary sector from which, according to FOURASTIÉ, there is a constant migration of manpower to the tertiary sector. Because of the general technical progress apparent in industry, it is possible, and indeed, usual, to pay higher remunerations to the reduced number of workers in the secondary sector. This is, to the railways, already a source of considerable difficulties as they are, at existing wages, no longer able to obtain labour for certain jobs because of the better pay offered by industry. This applies in particular to jobs which involve fatigue and danger, such as shunting. The railways must therefore try to balance the higher wages which they are forced to pay for that reason, by an increase in productivity. In other words, they must introduce technical improvements (which may call for major capital investments) so that the work is carried out with fewer but better paid men who have a strong sense of loyalty to the undertaking.

As explained at the outset, technical progress to-day stands under the sign of automation to which mechanisation is prerequisite. Both trends are mainly concerned with economic « mass activities » which are necessarily expensive and which are recurring every day. The railways, too, possess important establishments where such conditions occur. We may, in this connection, ignore the railway repair shops which are specific to the railways only inasmuch as they deal with railway vehicles. Their methods are the same as, or similar to, those of large factories so that the problems of mechanisation and automation are identical or similar to those of the machine industry. There is certainly a wide scope for technical progress which is, in fact, successfully pursued.

In contrast, there are certain « mass activities » characteristic for the *transport* side of railways. They occur at marshalling yards and goods transhipment depots : At the marshalling yard, freight trains are divided and re-formed into new trains according to destination. At the transhipment depots, « smalls » are unloaded and then loaded into other wagons, again according to destination. These operations can be divided into numerous part-operations to which it is possible to apply mechanisation and, in certain cases, also automation. Whilst mechanisation has already been applied successfully, over many years, to loading operations at goods depots and to train cutting operations in marshalling yards, the use of automation has so far been confined to one part-operation of train cutting, though this use already dates back thirty years. This part-operation concerns the automatic setting of points for wagons running down the hump, where the automatic operation is prepared by the storage of the switching instructions, and operated by the running wagons themselves. Whilst, for a long time, the introduction of automation, as a step beyond mechanisation, will still remain problematic in the sphere of loading operations and the formation of goods trains, the extension of automation to the entire process of train cutting at a marshalling yard is already possible now, as we shall presently see.

II.

The introduction of mechanisation into the marshalling of goods train dates back

to the early days of the railways, long before mechanisation was known in industry. In 1846, railwaymen invented the continuous method of train cutting when the method of pushing individual wagons was superseded by the method of letting the wagons of a goods train roll down from an inclined track into the group of sorting sidings. Around 1880, the wholly inclined track was superseded by the « hump ». The points were operated by hand or from a hump cabin by means of individual mechanical, later electrical, operation. Near the target, the wagons had to be stopped by means of drag shoes. In principle, this is still the method used to-day.

Further progress was made possible by the work of Dr. FRÖLICH, who succeeded in making this continuous operation more efficient while still adhering to the old principle of a free descent. The capacity increase was brought about by the adoption of a steep profile at the hump top and by a fan-like arrangement of the distributing points leading to the sorting sidings. Through this measure, the length of the common section used by all wagons (which differ greatly in respect of the speed which they can attain and the distance which they can cover under the influence of gravity alone) was reduced to a minimum, whilst the steeper ramp served to obtain a rapid acceleration of the wagons so that they were able to leave the common section of track more quickly. Both measures together tended to reduce the disturbing differences in running times which are apt to lead to the premature and undesirable catching up of one wagon by another.

The higher shunting speed thus made possible was still further increased by Dr. FRÖLICH'S invention of the heavy rail brake which made it possible to control the running speed and running distance according to the target and thus to prevent the nuisance of a premature collision. But the capacity increase thus obtained called for such a quick reaction in throwing the points that it is difficult for an operator to keep pace with the wagons at the first distributing points. This led, at the same time, to the automatic operation of the first distributing points, controlled by special hump cabins where, as already mentioned, these operations were programmed beforehand in accordance with the previously prepared shunting list.

The first of the mechanized installations of this type was introduced at Hamm in 1925 by Dr. FRÖLICH. This installation, in conjunction with the hydraulically operated rail brakes, was known as the « consistently mechanized hump installation ».

According to modern conception, however, this uniformity was still far from perfect although, at the time, one had every reason to be proud of the improvement achieved in one single move. For, automation was confined to a *part* of the switching operations, whilst mechanisation was confined to the hand-controlled preliminary braking at the bottom of the steep ramp. The services of the drag shoe operator in the sorting sidings were still required, and there still remained the gaps between the wagons in the sorting sidings, the consequential need for further closing-up work, and the risk of collisions in the sorting sidings. In the United States, the use of heavy rail brakes has been exaggerated inasmuch as several sets of brakes have been arranged in succession. It must be remembered in this connection that each subsequent set must contain twice the number of brakes as the one before, assuming *one* set of points to be located between them, so that the number already becomes four times as great if there are two sets of distributing points between them. In the American installations, the possibility of controlling the running of the wagons over a longer distance has therefore been bought at a very high price. In European installations, one has been content to use *one set* of heavy rail brakes which, for instance with

installations comprising 32 sidings, includes four brakes. In this connection, reference may be made to the article entitled « Vom Wesen der modernen Rangiertechnik » (« The essence of modern shunting technique ») in *Jahrbuch des Eisenbahnwesens 1951*. The American railroads have the further great advantage in hump shunting that, because of the more robust design of the vehicles, it is possible to admit four times the kinetic energy at the moment of collision, i.e. twice the maximum speed. Nevertheless, there remain, even there, gaps in the sorting sidings so that subsequent closing-up operations become necessary. Even in America, therefore, the problem of mechanisation has not yet been satisfactorily solved. In principle, the method is the same as ours, and can certainly not be regarded as automation.

The process of cutting a freight train with a view to placing the wagons, ready for coupling up, in a number of sorting sidings can be divided into a number of individual operations :

a) the wagon is uncoupled from the following wagon near the top of the hump;

b) the wagon is made to run down the hump over certain distributing points to the appropriate sorting siding;

c) on the way, the wagon is braked in a certain way and at certain points so that it does not catch up with the wagon running in front of it (interval braking) and does not reach the target at excessive speed (distance braking);

d) in the sorting siding, the wagon is closed up to the wagons already standing there, ready for coupling;

e) the wagon is coupled up in the siding.

As far as operations *a*) and *e*) are concerned, the uncoupling and coupling up of railway wagons in Central and Western Europe is still done in the same way as it was done a hundred years ago. Every time, a man must step between the vehicles, creeping through below the buffers. By means of a counter-threaded spindle, the coupling must be tensioned or relaxed, as the case may be, by the man turning the spindle several times by means of a handle. With a considerable physical effort, a shackle must be lifted by hand from or to a hook. This type of coupling is unworthy of the second half of the twentieth century. On the German Federal Railways, for example, some 450 000 goods wagons are shunted every day. If the fact that some wagons are handled in strings, i.e. remain coupled to each other, is taken into account by applying a group factor of 1.2, and if it is assumed that this will also cover the cases of secondary shunting where wagons may have to be uncoupled and coupled several times in the course of one passage through the marshalling yard, it follows that, on the German Federal Railways alone, some 375 000 times a day that a man must step between two vehicles to loosen the spindle, and just as many times to re-tension it.

In contrast, the railways of the United States, Canada and Mexico introduced the automatic centre buffer coupling as early as in the eighteen-nineties. In Japan, it was introduced about 1925, and in some parts of Soviet Russia already before World War II. And this in spite of the fact that it was in Germany that, in the nineteen-twenties, the best automatic coupling was developed in the form of the Scharfenberg coupling which permitted the inclusion, in the automatic coupling, of the air line of the through brake and, if necessary, also of electric circuits. America and Russia were content with the much cruder claw coupling which can only transmit tractive and buffer forces. Admittedly, resolutions have been adopted by the International Union of Railways (UIC) specifying the details of an European centre buffer coupling and the way in which it could be introduced. As yet, however, there is no positive decision to go ahead with this plan. And, because of the international transit traffic, it is necessary for the European Administrations to agree on this measure.

In any case, the technical problem of the automatic centre buffer coupling has been solved and the solution has been tried out abroad so that it is possible to apply automation to the operation listed under *e)* above. In contrast, it is not possible, at a reasonable cost, to arrange for automation in uncoupling (operation *a*). However, with an automatic centre buffer coupling, uncoupling can be carried out by hand very simply and rapidly from the side of the wagon.

Thus, if it is now intended to introduce automation into hump shunting, it is necessary to arrange for the wholly automatic working of all the operations *between a*) and *e*), i.e. from the gravity run from the hump top to the stopping of the wagon in the sorting siding, ready to be coupled up to the preceding wagon. In this case, the work of the drag shoe operators, rail brake operators and, *during* the running, also that of the cabin operator could be dispensed with.

The complete storage of hump shunting instructions for *all* points of the distributing zone has already been realized in the new hump shunting installation for the south-north direction of Gremberg marshalling yard. Here, the shunting list is used for the pre-storage, in a push-button operating desk, of the routes for the entire train cutting operation right down to the last distribution points. This procedure might be retained, but it would also be possible to go one step further by storing the information on a punch card and, with its aid, arrange for programme control of the operation. In any case, the point switching operation has thus become susceptible to automation.

However, the part that is more difficult from an automation point of view is the automatic, programme controlled braking of the wagons which must be so arranged that the wagons arrive at their destination at a permissible speed. Since the heavy rail brake was created in the nineteen-twenties, the seemingly obvious solution was to try and use this brake for regulating the speed of the wagons in such a way that the wagon came to a standstill at the desired target point.

In addition to regulating the interval between wagons passing through the switching zone at different speeds, it has always been the function of the heavy rail brake (which is built in at the bottom of the hump and therefore known as « valley brake ») to take into account, in the degree of braking applied, the distance to be covered by the wagon which depends on the occupancy of the siding. But the distance and interval requirements are often conflicting so that, even for this reason alone, it is not possible to use the valley brake for perfect target braking at a satisfactory hump shunting speed. If the introduction of target braking is to bring about the automation of hump shunting, it would be necessary for each wagon to be released from the target brake at such a speed that it arrives at any, freely selectable point of a sorting siding at a speed not exceeding 1 m/sec. This must be possible while adhering to a permanent hump shunting speed of at least 1 m/sec. This solution has long been thought possible as the valley brake, when operated by an experienced operator, could already be controlled so well by hand that, in a great number of cases, the wagons could be placed in the sidings with fairly high precision. But all the labour and mental effort concentrated on target braking is unfortunately just as futile as was, at one time, the search for the perpetual motion or the quadrature of the circle. This solution must unfortunately be ruled out for physical reasons.

True, the study of American hump shunting installations had given rise to the opinion that target braking had been realized there. This is because one had, in some cases, dispensed with the final braking by means of drag shoes or hand brakes. But, as already mentioned, conditions over there are different. There is a

considerable array of consecutive rail brakes, and there are robust standard type wagons with fairly uniform running characteristics, fitted with well sprung automatic centre buffer couplings which can absorb four times the kinetic energy of a collision permissible under European conditions. Compared with European conditions, this represents a considerable relaxation of the requirements on hump shunting dynamics which obviously results in a simplification. How much easier would be the task of European shunting technique if the wagons to be handled were built in such a way that a colliding speed of 2 m/sec could be admitted, instead of having to deal with these weakly structures which, in an outdated and uneconomic way, tend to prejudice the introduction of mechanisation and automation into large-scale hump shunting. But even in the American marshalling yards, there are still many gaps in the sorting sidings, and the amount of damage caused by shunting collisions is stated to be great. This American method of operation can therefore not be regarded as genuine target braking where the speeds are accurately controlled right up to the point of destination.

As early as 1938, it was found by Dr. KRIESCHE, in a thesis prepared at Karlsruhe Technical University, that the potentialities of target braking are strictly limited even in theory. This study should have had the effect of deterring others from further efforts to attain genuine long-range target braking, and of making them content, provided that only one set of valley brakes is used, with a preliminary braking at the valley brake which takes the distance requirements into account as much as possible.

But KRIESCHE's work was difficult to understand and had little practical effect so that, in some expert circles, the hope for genuine target braking was revived by the modern requirements of automation, until the problem was eventually reviewed once more by the Expert Committee for Shunting Technique of the German Federal Railways who proved the impracticability of genuine target braking, especially under European conditions.

The principal reasons why genuine target braking is not practicable are the following :

1) *long-range* target braking (extending over 100 m or more beyond the clearance point of the last distributing point) must be ruled out because of the reduction in hump shunting capacity caused by the minimum interval requirements in each sorting siding. This is because, over a long running distance, there occurs the strange phenomenon of the bad runner tending to catch up with the good runner. For, in the case of a long-range target, the bad runner must be given a very high initial speed whilst the good runner running down the gently inclined siding requires only a low initial speed in order to arrive at the remote point of destination at a permissible speed. Initially, therefore, the bad runner runs at such a high speed that it would be able to catch up with the good runner unless the headway in front of it is very great, and that can only be arranged at the expense of hump shunting capacity;

2) if target braking is to be carried out with one set of valley brakes only, i.e. so that there still follow a number of distributing points, target braking also becomes impracticable for closer targets, because the wagons would have to pass the switching zone at such a low speed that the hump shunting capacity would again be reduced to an intolerable degree;

3) from an operating point of view, the only possibility of target braking lies in the use of two sets of brakes for short-distance targets, where one of the sets would be the existing valley brake whilst the second set would have to be provided in the form of special target brakes beyond the last distributing point. With this arrangement, an adequate shunting capacity would be ensured provided that the

running resistances are sufficiently well known and adequate control is possible. However, in view of the short range of the sorting zone which would be confined to about 50 to 80 m, frequent clearing operations would be necessary. These operations could not be carried out by a locomotive working on the side of the hump as this would lead to unduly frequent interruptions of hump shunting operation which would again entail an intolerable reduction in shunting capacity. From an operating point of view, two-stage target braking for close targets is therefore only possible if the sorting sidings could be cleared by special devices which do not impede the hump shunting operation. But such devices are extremely expensive and would still have to be developed;

4) finally, it must be remembered that the running resistances of the wagons show a pronounced scatter so that target braking would be prejudiced by a further, inevitable factor of uncertainty which would, even on its own, preclude the application of target braking to distant targets.

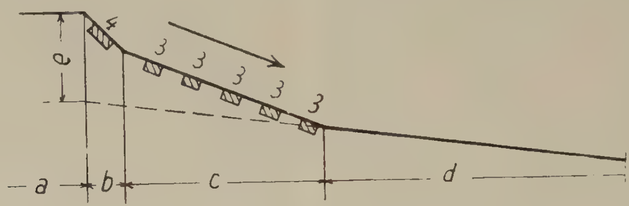

Fig. 1.

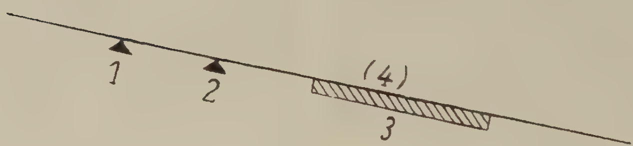

Fig. 2.

III.

Although it must be accepted that automation of hump shunting can in practice not be achieved with the aid of target braking, there is still no reason to abandon the idea of automation. In fact, automation of wagon sorting through hump shunting has now become possible, though on the basis of a totally different principle. The practical development of this type of automation is at present being undertaken by the German Federal Railways and will shortly be completed. This method is based on the collection of wagons by means of a *chain of rail brakes*, consisting of a major number of very small and very light braking devices spread over the collecting zone. For this purpose, it is necessary to raise the tracks of the switching zone with the distributing points leading to the sorting sidings to a certain extent, to give the initial sections of the sorting sidings a falling gradient which decreases from steep to moderately steep, and to equip these inclined sections with this very light type of rail brakes. Whenever the speed of

approaching vehicles is unduly high, these brakes are brought into action by means of rails contacts and relays, and are again released when the vehicle has passed over them.

Figure 1 shows the longitudinal profile of the rail brake installation, whilst figure 2 shows the arrangement of the rail contact controlling a brake. As figure 1 shows, the horizontal tracks of section *a* of the switching zone, comprising the distributing points leading to the sorting sidings, are raised by the measure *e*. The following sections *b*, *c*, and *d* of the sorting sidings are given falling gradients so that section *c* has the gradient corresponding to that of the so-called gravity yards where nearly all wagons begin to move on their own, whilst the gradient of section *b* is so steep that all wagons are certain to move off on their own, and the gradient of section *d* corresponds to the slight gradient of 2 ‰ prescribed for sorting sidings of flat yards. Track sections *b* contain rail brakes of a light to medium-heavy type (4) controlled by rail contacts and relays which are intended to bring the wagons arriving from the switching zone *a* nearly to a standstill. In contrast, the « chain of rail brakes » built into track section *c* consists of a number of very light, fixed braked (3), which are likewise controlled by rail contacts and relays and have the function of slowing the wagons down to such an extent that these enter section *d* with a speed not exceeding the permissible colliding speed of 1 m/sec. Here, the wagons finally come to a standstill, either on their own, or through their impact with the wagons already standing there. For instance, if the first wagon entering section *d* of a track has come to a standstill at a point half-way down, and if

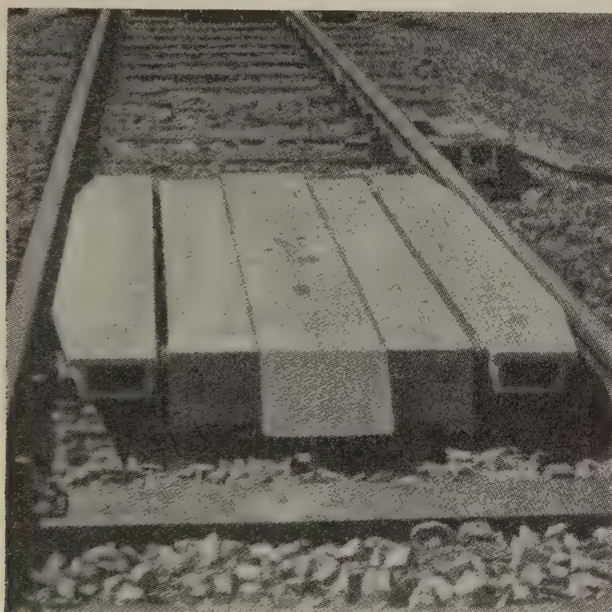

Fig. 3.

subsequent wagons have occupied this section up to the lower end of section *c*, the next wagon will come to a standstill on the last rail brake of that section, and further wagons will come to a standstill in front of it up to that point of section *c* where the aggregate pressure of the wagons standing in section *c* begins to exceed the aggregate running resistance of the wagons standing in section *d*. the weight of the string of wagons in section *c* is heavy enough to push the wagons standing in section *d* further down that section up to a distance of 370 m. With a difference in height of e = 80 cm and a length of section *c* = 150 m, the weight of the string of wagons standing in section *c* would be sufficient to push the wagons in section *d* to a distance of 550 m.

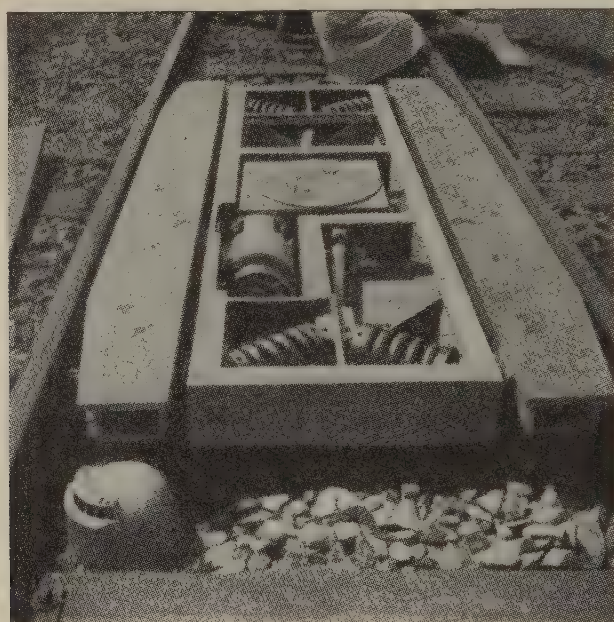

Fig. 4.

From that moment, the wagons standing in section *d* will be pushed further by the pressure of the wagons standing in section *c* so that the track sections *c* and *d* are filled with wagons up to a given or desired limit.

It can, for instance, be worked out approximately that :

if the difference in height e = 45 cm
the length of section b = 10 m
the gradient of section b = 6-7 $^0/_{00}$ and
the length of section c = 100 m,

The time-controlled automatic control of each rail brake (fig. 2) is so arranged that, whenever an axle passes the rail treadle 1, a time relay is energized. If the axle passes the short section between treadles 1 and 2 at excessive speed, i.e. within too short a time, the passage of the axle over treadle 2 has the effect of bringing the rail brake into operation. In addition, a second time relay is energized which, after a pre-set time lag corresponding to the duration of the

braking, returns the rail brake to the release position. If the time taken by the axle to cover the distance between the treadles 1 and 2 is comparatively long, and in consequence, the speed of the wagon is low, the first relay cuts out after the lapse of the pre-set time lag, and the brake remains inoperative. The process is repeated for each separate axle, the brakes being so short that only one axle of the wagon can be on the brake at a time.

Figure 3 shows one of the light type of « chain brakes » of section *c* in the inoperative position, covered up and ready for operation. Figure 4 shows the brake open, in the same position, whilst figure 5 shows the brake in the braking position. The brake is of the beam type, acting exclusively in the outward direction against the inner flanks of the wheels, and operated in either direction by a light electric motor by means of a toggle drive. The power required for this drive is very small as it is only required to overcome the friction in the bearings. The braking power itself is generated by the entering axle which presses the brake beams inwards against the springs visible in figures 4 and 5 which are thereby tensioned. There is therefore no need for any extraneous energy supply to provide the braking power. Figure 6 shows the trial installation of the German Federal Railways with a chain of seven brakes of section *c*, and *one* part of the medium-heavy preliminary brake in section *b* (4) which, for certain reasons connected with hump shunting dynamics, has been divided into *two* parts.

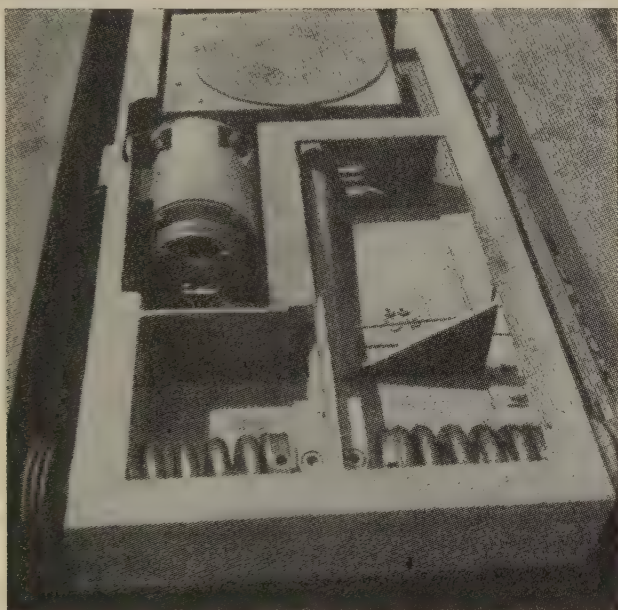

Fig. 5.

Now, the wagons running down the hump must be so retarded in the valley brake that they arrive at the preliminary brake of the chain at a speed of between

3 and 4 m/sec. This is a simple requirement which can easily be met by the valley brake at any time, and which permits of a high through-put speed in the switching zone. The operation of the valley brake is considerably simplified as it is no longer necessary to take into account differences in running times. The preliminary brake of the chain, (4), has the function of slowing down the vehicles to the harmless speed of about 1 m/sec and passing them on, at that speed, to the section *c* with the chain of brakes. It is not proposed to discuss here the details of circuits and wiring; they offer no problems which cannot be overcome with the present means of relays technique. It may merely be mentioned that the reaction of the preliminary brake in section *b* is partly also con-

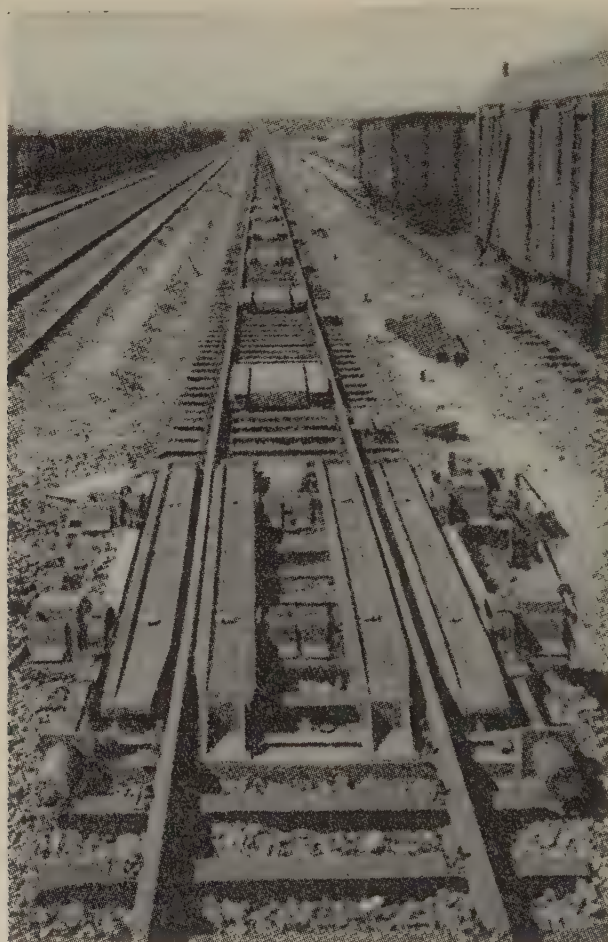

Fig. 6.

ditioned by the axle loads which are previously tested automatically.

Figure 7 shows, plotted against the longitudinal profile of a hump installation with a chain of rail brakes, the speed/distance diagram for a wagon running down from the hump. Pushed over the hump at a speed of 1 m/sec, the wagon « good runner » for which the always constant braking power of the chain of brakes is designed. The brakes always absorb as much energy as the wagon has gained in the interval between two brakes. The diagram is somewhat simplified inasmuch as the saw-tooth line of the actual speed/distance diagram will have two,

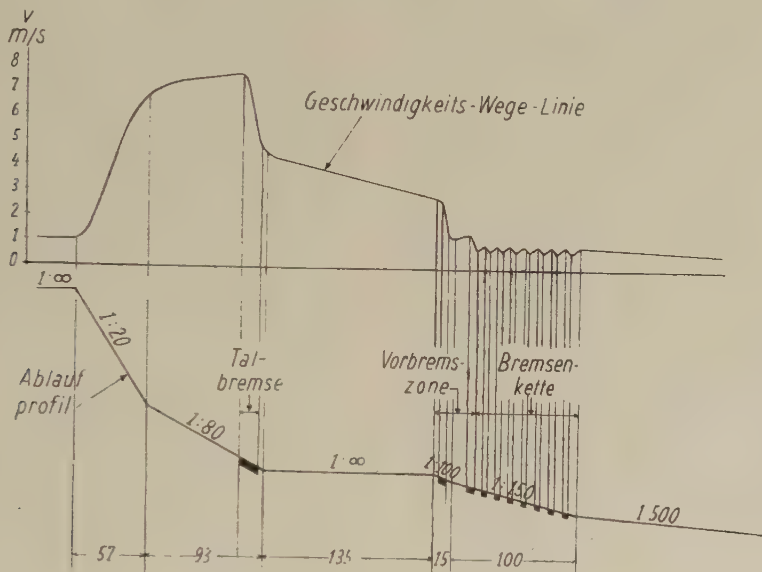

Fig. 7.

Explanations of German terms :

Geschwindigkeits-Wege-Linie = speed/distance characteristic curve. — Ablaufprofil = hump profile. — Tlbremse = valley brake. — Vorbremszone = preliminary braking zone. — Bremsenkette = chain of brakes.

runs down the steep ramp with a high initial acceleration which is subsequently reduced on the intermediate gradient of 1 in 80. At the valley brake, the wagon is slowed down according to its running characteristics and passes through the remaining 135 m of the switching zone at an adequate speed. At the two parts of the preliminary brake, the residual speed of 3 m/sec is reduced to about 1 m/sec at which the wagon is passed on to the chain of brakes. The diagram (time/distance) shown in the illustration corresponds to the running of a heavy four or more times as many zig-zags according to the number of axles. The diagram must therefore be regarded as merely qualitative and serving as an illustration. A light wagon will not show such a speed characteristic fluctuating around 1 m/sec within the braking zone, but will be repeatedly braked to standstill, resuming its run down the heavier gradient as soon as the brake is released. No harm is done if wagons catch up with each other in this zone. All that will happen is that the good runner will push the bad runner, or that a heavy wagon will push

a lighter one. On the gentle gradient of 1 in 500 beyond the last brake of the chain, the wagons roll out slowly, or they form up later, in the manner already described, under the influence of the excess weight of the wagons still standing in the braking zone, a string of wagons standing buffer to buffer. Wagons pushed over the hump in strings are dealt with in the same way since every axle causes the same relay operations and corresponding braking reactions.

Meanwhile, the electrically operated remote control of the heavy valley brake and the automation of this control have been developed by the German Federal Railways to such an extent that it will soon be possible to replace the brake operator by a fully automatic device.

Owing to the systematic research work carried out by the German Federal Railways, the problem of the *automation of the entire process from the uncoupling of the wagon* to its closing up in the siding, ready for coupling up, has thus been *solved,* and a long-standing aim of shunting technique has been finally attained. If it would also be possible to introduce the automatic centre buffer coupling, it would now be possible, without any further intervention of a human being in the sidings, to re-form a train, ready for departure, fully automatically merely by pushing it down the hump, provided of course that there is no need for any secondary shunting operations for a train containing several destination groups.

Given mass production conditions, it should be possible to reduce the cost price of the light brakes used for the brake chain to such an extent that their use becomes an economic proposition. Man-power now required for the laying of drag shoes and the operation of the rail brakes will be saved and can be diverted to other fields, so that productivity is increased. Moreover, owing to the careful speed control, there will no longer be any cases of damage to the vehicles and their loads due to shunting collisions, which is a further contributory factor tending to make the installation an economic proposition. All that is necessary now is to carry out a *large-scale trial* with these new installations.

In the same way as in other economic spheres, modern progress is mainly based on scientific research, such research entails, as it does in this case, technical perfection and economic benefit to the railway. In all economic spheres, and certainly with the public transport undertakings, research is a necessary condition of survival.

[656 .212 .5 (73)]

Special report on the significance of Operations Research for the railroad industry.(*)

(*Reprinted from American Railway Engineering Association* (AREA), Bulletin No. 532, November 1956.)

The purposes of this report are as follows:

A. — To explain briefly what Operations Research is.

B. — To give some examples of problems in the railroad industry for which Operations Research is well adapted.

C. — To discuss the feasibility of individual railroads using Operations Research as part of a general research program.

A. — WHAT IS OPERATIONS RESEARCH?

1. Operations Research is the application of the scientific method to problems which arise in some organizational setting. It is concerned with management problems, and as such is an aid in making management decisions. Operations Research is concerned with the same sorts of problems which traditionally have been the interest of industrial engineers, production and financial executives; in short, with the area of management engineering.

2. Historically, O. R. received its major impetus in helping in the solutions of military problems. The term was first used to describe the methods employed by the British Air Military Research Station in determining the best ways in which to employ various forms of radar equipment in World War II (1). Success in the radar field led to similar activities in air warfare, and anti-submarine detection and warfare measures. O. R. was used also by the United States both for naval problems and problems of logistics. At the end of World War II, the armed forces of the United States continued to promote the development of O. R. methods, and today large O. R. groups continue to work on military problems for the Air Force, the Navy, and the Army.

3. It was not a difficult step from purely military applications to industrial applications. Today many firms have O. R. teams as part of their permanent staff. Many other firms use consulting organizations to provide the services of O. R. groups. Universities such as Massachusetts Institute of Technology, Johns HOPKINS, The Case Institute, Carnegie Institute of Technology, to mention only a few, have active research underway on many kinds of O. R. problems. Typical of such problem areas are those of production scheduling, inventory control, plant and warehouse location, cost and other forms of accounting control, maintenance programming, equipment utilization and other problems of management. It is more fruitful to view O. R. as part of the normal development in the field of

(1) See « Reflections on Operations Research » by E. C. WILLIAMS, November 1954, « Journal of the Operations Research Society of America ».

(*) This report was prepared from an original paper by R. R. CRANE, manager of research, management Sciences, TOUCHE, NIVEN, BAILEY & SMART, and H. H. WEIN, associate professor, head of transportation group, Carnegie Institute of Technology, both members of Committee 16, by a special subcommittee consisting of Q. K. BAKER, chairman, R. R. CRANE, W. J. HARLOW, J. E. JAY, R. L. MILNER, F. N. NYE, Geo. RUGGE, D. K. VAN INGEN, and H. H. WEIN.

management science rather than a new field of endeavour.

4. Essentially the feature which distinguishes O. R. from other methods of attacking management problems are the tools and scientific philosophy which O. R. teams apply to these problems. The methods which O. R. groups use are not the traditional tools of industrial engineering or accounting, though both these disciplines might be included in an O. R. team [1]. The advanced techniques generally used by O. R. are based on three great developments which became more widely recognized in the mid-thirties. These are: *a*) the extension and refinement of statistical methods to industrial problems [2]; *b*) the more intensive application of mathematical methods to industrial problems; and *c*) the development of high-speed methods of computation. Any example of O. R. work, whether it is a problem drawn from business, government, or the military area, will be found to include techniques drawn from one or all of these fields. The specific tools used in these problems may involve relatively simple techniques such as regression analysis, or more advanced techniques such as sampling theory, queuing theory, linear programming, quadratic decision programming, game theory, Monte Carlo methods, and other related methods. The advantages of these techniques are that great power is obtained in data collection, interpretation and analysis of problems which in most cases it is simply not possible to obtain with any other methods. Problems involving many variables and their inter-relations can be handled with precision and economy.

5. It is important to stress, however, that tools and techniques by themselves are not enough for successful O. R. As a consequence, the device of an *O. R. team* is almost universally employed rather than an *O. R. individual*. The teams require not only those who are adept in the use of these advanced tools, but also those who have intimate knowledge of the company and industry, including the administrative and institutional details and the engineering, financial, personnel, or sales aspects of the particular problems. Without such team balance, O. R. will be handicapped, and its solutions will lack the elements of realism necessary in any working solutions. The knowledge required in statistics, mathematics, or high-speed computing is sufficiently complex so that in general one will not find that a single individual will be sufficiently skillful in all three fields, let alone having command of the institutional or practical elements of the problem. O. R. teams will thus consist of several technical specialists in the O. R. tools and specialists in the substantive elements of the problem. The problem of the best size and composition for O. R. teams for the railroad industry is treated in Section C.

6. *How Operations Research works.* — Perhaps the best way to gain insight into the difference in approach of an O. R. team and conventional methods is by use of an example. The following simple example is purely hypothetical.

Suppose a railroad management is interested in improving the service of its crack freights — which we designate the Red Ball freights (RB). Let us define « improving the service » very simply as increasing the frequency of times that the RB's are on schedule or better. The management considers various measures, say A, B, C, etc. After discussion it selects measure A as the best — on the theory that A will give the highest percentage of on-time or better performance. It puts A into practice and tallys the results, as shown in Table 1.

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[1] See HERMAN and MAGGEE: « Operations Research for Management », Harvard Business Review, July-August 1953, on the methods of industrial engineering and O. R.

[2] The development by Walter SHEWHART of « Statistical Quality Control » over two decades ago, may be viewed as the forerunner of the application of statistical methods to industry.

TABLE 1.

Performance of Red Ball freight trains.

Day	*Percent of On-Time or Better Before Measure A*	*Percent of On-Time or Better After Measure A*
1	56	82
2	65	95
3	70	93
4	68	96
.		
.		
.		
100	70	92
Average	65	95

Clearly, measure A seems to have worked. Would an O. R. team approach this problem in any different manner? The answer is *yes,* it would. The first question they would raise is as follows:

Question 1. — Is the objective solely to improve the service of the Red Balls, with no other conditions on that improvement?

Answer to Question 1. — Clearly there are other conditions for improving the RB. They should be economical and not deteriorate other train service.

Question 2. — How do you know that the service of other trains has not deteriorated as a result of the measure A?

Answer to Question 2. — Well, we really don't know — but we see no reason for this to occur.

At this point, the O. R. team formulates a hypothesis which will test the validity of answer 2 and Table 1. This hypothesis is:

a) The services of other trains (OT) (where service is defined as percent of time of other trains meeting schedules) is a function of the percent of time the RB meet their schedule. Or in shortland: (1) $OT_s = f\ (RB_s)$. After some work, they come up with a *revised* Table 1, as follows:

TABLE 2.

Day	*Percent of Time RB on Schedule or Better, Before Measure A*	*Percent of Time OT on Schedule or Better, Before Measure A*	*Percent of Time RB on Schedule or Better, After Measure A*	*Percent of Time OT on Schedule or Better, After Measure A*
1				
2				
.				
.				
.				
.				
Average	65	60	95	38

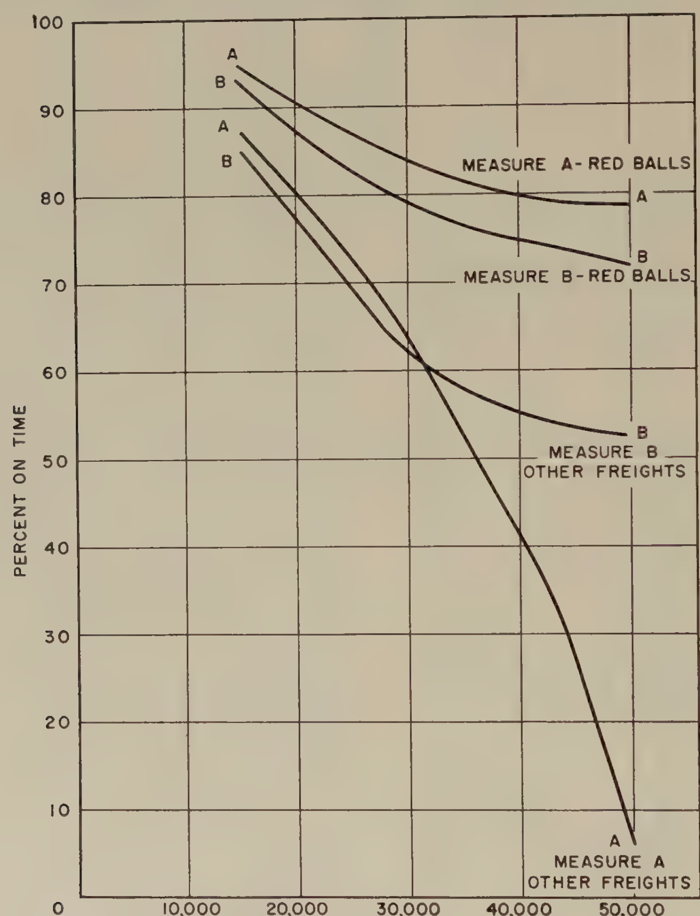
Revised Table 1 (Table 2) shows a different picture from Table 1, for it is clear that though measure A has improved the service of the RB freights, the service of other freights show marked deterioration. The O. R. team applies statistical tests of significance to the data which show that the deterioration of the OT's could be attributed to chance factors in less than 1 time out of 100. Their problem now really begins. They have shown that measure A with high probability has adverse effects on the OT's. Two basic problems remain: (1) Can the effects of the measures be determined in advance of putting different measures into effect? (2) How much deterioration in the OT service is management willing to accept for every one percent increase in on-time or better arrival of RB's. They form several other hypothesis, or in O. R. language, models. These models in effect state in a mathematical way the dependence of on-time or better arrivals of any train on the measures applied to that train and all other trains, and upon the daily car flow of the system. In determining and testing these models various techniques, such as statistical sampling, Monte Carlo procedures, and other statistical and mathematical techniques, are used. After this work, their results can be shown in Chart 1. This shows the effects of two measures on on-time or better arrivals of the RB freights and the OT

freights as traffic volume is allowed to vary over the probable range of 15 000 to 50 000 cars per day.

Chart 1 now gives management the information it needs to make a more rational amount of traffic which the road is handling. As the chart shows for any valuation of service for RB's and OT's, measure A is the best to employ up to 33 000 cars per day traffic. Beyond that range the

CHART I.

EFFECT ON SCHEDULE OF VARIOUS MEASURES.



DAILY CAR VOLUME.

choice. What it shows is that if a value is placed on all trains (not only RB's) falling within some service range, the best measure will vary depending upon the service of the OT's falls very rapidly under A — much more so than the service of the RB's falls under measure B. Given any valuation, the better of the two poli-

cies can be adopted. The rule might state : adopt measure A up to 33 000 cars per day volume; adopt measure B, thereafter.

Summary.

The first step in solving any operational problem is thus to clearly define the problem. The second step is to obtain adequate operational information. The third step is to analyze this information and develop a theory of how the operation works. The fourth step is to apply the results obtained from the theory to the actual operation.

Frequently people realize they have a problem but cannot express it except in general terms. In this case, the researcher must first « find » the problem and define it clearly and specifically. To do this and carry out the second step, he will use available operational data or, where necessary, gather his own information.

The next step in the solution is the development of a theory of how the operation works. Using this theory the scientist may rapidly and inexpensively investigate the effects of varying many of the factors which enter a problem and frequently determine the best arrangement of physical facilities or procedures for the objective of the operation.

The final step is changing the operation to produce the results desired as predicted by the theory.

The outstanding limitation of this technique is that all theories are only approximations of the actual operation. First you simplify and then develop the theory to get a clear understanding of the problem. The theory can serve only as an aid in obtaining the solution, and one must always be careful when using the results of the theory that some requirement inadvertently left out of the theory for one reason or another, such as the Car Service Rules or an ICC regulation, does not make the results inapplicable.

B. — EXAMPLES OF SOME RAILROAD PROBLEMS THAT CAN BE MOST EFFECTIVELY HANDLED BY O. R.

Following are some problem-areas and related specific examples of railroad problems drawn from freight operations which, it is believed, can be effectively attacked by scientific methods.

Utilization of rolling stock.

The railroads move material of one kind or another in cars in trains of various lengths and tonnages at varying speeds via many routes from many geographical locations to many others. The average turn-around time from loading to loading for a freight car is about 15 days. Of this 15-day period, less than 10 % is spent actually accumulating the ton-miles for which the railroads are paid. If normal freight line-haul speed were maintained from origin through to destination, the average travel time would be less than 12 hours. Decreasing turn-around time is a way to increase car utilization and improve the service to the shippers. The following examples are directed at ways of decreasing freight car turn-around time.

a) *The distribution of freight cars.* — On a national or a system-wide basis when the day to day variation of car requirements and availability is fairly constant, some improvement in the process of distributing freight cars which would lead ultimately to decreased turn-around time could be obtained through the use of linear programming. Linear programming is a mathematical technique which was developed previously by the Air Force since World War II to assist in solving problems in the supply of men and equipment. A detailed description of the application of linear programming to a simplified car distribution problem is given in Case 1. Much more complicated situations with many added conditions can be solved by this method.

b) *Classification yard operations.* — Cars

spend a large percentage of their time in yards. The theory of queues can be applied here to predict the effect of changing the number of yard inspection crews, the rate at which cars can be humped, and the number of switch engines used. The cost of adding or subtracting facilities is balanced against the decrease or increase in average car delay in the yard or terminal to obtain greatest economy.

c) *The distribution of classification effort between yards.* — A problem with which railroads are faced is the determination of the proper degree of classification work to be carried out at key yards. A simplified example of a problem of this type is given in Case 2. Here two classification yards with different car handling capacities are considered, and certain conditions of classification for ultimate destination are specified. The value of the techniques used in this special case only becomes clear when an attempt is made to solve complicated actual problems. Many operating problems of this type cannot be solved adequately except by special methods. In Case 2 programming and queueing theories are employed.

Maintenance.

Railroads must maintain the roadway over which the trains pass, the rolling stock that moves over the roadway, the motive power and the many other railroad facilities. The most economical cycling of overhauls and the desirability of preventive maintenance are problems which have been studied in other industries by scientific methods. These methods also can be applied on the railroads to their maintenance problems. Following are several specific problems :

a) *Replacement of rail.* — A number of questions immediately arise in connection with the replacement of rail by new or partly used rail. One important maintenance problem is the determination of the most economical time to replace a lot of rail of a given age. It is well known that individual rails wear out at different rates, and consequently some rails must be replaced before others. For a special case, the most economical time to replace the entire lot of rail, while recognizing the necessity of replacing individual rails as they wear out, is given in Case 3.

b) *Preventive maintenance.* — Preventive maintenance performed on such railroad equipment as rolling stock and motive power will decrease in-service failure. For example, a Diesel engine might be thoroughly overhauled every 4, 6 or 8 years, whichever is the most economical interval.

c) *Hot boxes.* — To what extent are hot boxes related to maintenance procedures and to what extent are they related to mechanical design ? With the aid of failure theory, a critical examination of operational data on hot boxes can help answer this question. One specific application of failure theory to hot boxes is in the evaluation of such individual maintenance practices as servicing only those journal boxes which, after inspection by a qualified man, are determined to be in poor condition, rather than servicing all the journal boxes, as is frequently done. In some instances this procedure has appeared to decrease greatly hot box set-offs.

There are many more problem-areas and specific problems which will occur to the railroad man, once the capabilities of scientific research on operations are recognized. This research may be applied to many railroad departments. Possible areas are the location and design of new facilities (such as yards and track layouts), and the information transfer and processing systems which are becoming increasingly more useful in the railroad operations. Advance recognition of the proper design of such expensive facilities as these is necessary to assure that the railroads obtain the facilities best adapted to the purpose. The design of facilities requires a clear understanding of the operational requirements as well as a familiarity with technological developments. Another area is the design and installation of terminal systems and cost control.

Following are some more detailed, though

greatly simplified, examples and railroad problems which can be approached by O. R.

Case 1. — Freight car distribution.

One mathematical technique for solving problems of distribution is called *linear programming*. The movement of many items to many places at specified times in such a way that the cost of movement in time or money is a minimum is a problem of programming.

Linear programming is of recent development, relatively speaking. Application of this technique to industry has been fairly extensive. It has helped solve such problems as the proper composition of feed mixes for animals, problems in production scheduling and in transportation. Only a much simplified case of the distribution of empty freight cars will be given here, but it is perfectly possible to solve much more complicated situation with many added conditions.

In this example seven locations are considered, which may be thought of as separate cities, metropolitan areas, or whatever. In fig. 1 they are shown as locations A, B, C, D, E, F, and G. Confining our attention to the first day, the three origins, A, B and C, have, respectively, 9, 4 and 9 empty (or surplus) cars which must be distributed to fill the request for empties at four destinations, D, E, F and G. In other words, the problem is to distribute the surplus cars from the origins to the destinations so that each destination will obtain the number of cars required, and in such a way that the cost of the movements will be the lowest possible. The cost of hauling a car from one point to another is shown in the lower table of fig. 1. It is seen from this cost table that the cost to move one car from location A to D is 5 units (dollars); the cost to move a car from A to C is 16 units. The cost to move a car from A to A, or from any position to itself is of course zero.

The railroads, of course, must make these car distributions every day, but there is some question whether this is done at minimum cost, especially when there are a great many origins and destinations. The method of linear programming assures that the cost will be optimum.

LINEAR PROGRAMMING FOR EMPTY FREIGHT CAR DISTRIBUTION

Empty car sources, and requirements for cars

LOCATION	1st DAY	2nd DAY
A	+ 9	— 5
B	+ 4	+ 3
C	+ 9	+ 4
D	— 4	+ 7
E	— 8	— 7
F	— 3	— 5
G	— 6	+ 3

— DEFICIT + SURPLUS

	A	B	C	D	E	F	G
A	0						
B	12	0					
C	16	4	0				
D	5	15	3	0			
E	3	17	2	9	0		
F	1	3	1	4	5	0	
G	9	2	8	3	7	2	0

COSTS OF DISTRIBUTING CARS

Fig. 1.

Still dealing with the first day alone, the movements as determined by the application of linear programming are shown by the upper left hand chart of fig. 2. The four empties available at origin B are moved to destination G, filling part of G's requirement for 6. The other 2 cars for G are sent from location C, which also sends 4 and 3 to D and E, respectively, using up C's total surplus of 9. Note that only 8 of the 9 surplus cars at A are moved, one being held at A or « stored ». This

SHIPPING TABLES

LOWEST COST FOR DAY-TO-DAY BASIS

1st DAY

From	TO D	E	F	G	Store	Total
A		5	3		1	9
B				4		4
C	4	3		2		9
Total	4	8	3	6	1	22

COST = 60

2nd DAY

From	TO A	E	F	Store	Total
B			3		3
C		4			4
D	4	2		1	7
G		1	2		3
Total	4	7	5	1	17

COST = 66

USING KNOWLEDGE OF BOTH DAYS

1st DAY

From	TO E	F	G	A	Total
A	2	2		5	9
B		1	3		4
C	9				9
Total	11	3	3	5	22

COST = 35

2nd DAY

From	TO D	G	E	F	Store	Total
B				3		3
C			4			4
D	4			2	1	7
G		3				3
Total	4	3	4	5	1	17

COST = 25

TOTAL COST = 60

Fig. 2.

comes about because there were a total of 22 empties available, but only 21 were required on this day. Special consideration of Car Service Rules and orders have been omitted.

The cost of this first day's movement is computed by multiplying the number of cars in each movement by the cost as shown in the table of fig. 1, and adding the cost of all movements. For example, the cost table shows a cost of $ 3 to move a car from A to E. In the solution, 5 cars were

so moved at a cost of $ 15.-- Add to this $ 3 required to move 3 cars from A to F at $1 per car, and so on for all movements. The total cost for this example is thus $ 60.

The car surpluses and requirements for the second day are also shown in fig. 1, and the linear programming solution, obtained by exactly the same process as the first day, is given in the upper right-hand chart of fig. 2. The minimum cost for the second day is 66, or a total of 126 for the two days' movements, each handled independently of the other.

Now in practice, a railroad often knows empty car requirements and availability a day or more in advance. The second example, shown in the two lower charts of fig. 2, assumes that on the first day the surpluses and requirements for the second day are also known, and this information is taken into consideration in the solution. The total cost for the two days combined is now 60 — a startling reduction from the day by day total of 126. It is necessary to insert a word of caution here — one cannot generalize that a 50 % reduction will always occur when information on succeeding days is taken into account. The total cost for two days considered together will usually be less, and never more, than for the two days considered separately, but the gain will be of varying magnitude.

So far we have discussed only movements for minimum cost and have said nothing about the time required to supply the shipper or location with cars.

Let us make the assumption that the surplus empties are released at the origin at 5 p.m. and that cars are needed at the destinations at 8 a.m. on the following day. Let us further assume that the time required to move from the origin to a destination is proportional to the cost as given in the cost table of fig. 1. Then the average cost in time, or lateness after 8 a.m. is 4 h and 27 min over the two days in the example where each day is handled separately. In the cost-saving case of two days handled together, the average cost in time is 4 h and 41 min — an increase of only 14 min per request filled. The savings in cost was obtained at the expense of some loss in time, but this loss is relatively small. In fact, looking at the individual times instead of the averages, four destinations had to wait varying times up to 30 h in the case in which the two days were solved one at a time; while in the solution for two days simultaneously, only 3 destinations had delayed arrivals and the maximum was 24 h. Thus, in terms of *maximum* delay, rather than average, the simultaneous two-day solution is actually better as well as less expensive; this will not always be the case, however.

The technique of linear programming may be adapted to the car distribution problem on a nation-wide scale as well as to the day-by-day local movements.

Case 2. — Analysis of a classification yard.

The second case to be discussed is the application of queueing theory, or waiting line theory, to the operation of a classification yard. The problem was to find the effect of changes in operating procedure on the average time a car remained in the yard.

A queue is a group of items which are standing in line to be processed. For example, people standing in line to have their groceries checked, or standing in line at a passenger ticket office, constitute a queue. The theory of queues has been developed extensively and with increasing rapidity since World War II, although the theory had already been used to some extent in telephone trunking problems a number of years earlier.

Fig. 3 shows a simplified model of train flow through the receiving and humping part of the classification yard under study. It is seen that after arrival in the yard a train waits an average of 65 min before the inspection begins. Inspection itself requires an average of 71 min, after which the train is again required to wait 160 min before being classified or humped. The

humping process takes only 25 min on the average. The paper work process is seen to start as soon as the train arrives and requires an average of 80 min for completion. This is considerably less than the sum of 65 min pre-inspection wait and the 71 min inspection, so that in this yard paper work was seldom a bottleneck.

The first thing one notices is that this 160-min pre-classification wait is somewhat large, particularly in view of the short (25 min) time required for the following classification process. However, while the average time to hump a train is 25 min, this work can only go on while the switch engine is on the job. The full time required to classify a train may be thought of as the sum of the time the switch engine actually spends in the bottom making shovedowns, trimming, etc.

Now, unfortunately, train arrivals at yards are not very well behaved, mathematically speaking, and trains arrive in a sort of random, but not purely random, fashion. Yard processing rates follow no simple rule, and in addition we see on this flow chart two queues (pre-inspection wait, and pre-classification wait) in series. We know of no theory to handle this type of situation, and hence a computational technique called the Monte Carlo Method was used.

The Monte Carlo Method is so called because it uses random numbers to generate, in this case, the arrival times and sizes of trains, the latter determining the humping times. One can use this technique to reproduce a random sample or « run » of the entire classification process in order to obtain, under various conditions, the number of trains waiting in the two lines and the time they have to wait.

SIMPLIFIED TRAIN FLOW CHART
FOR A CLASSIFICATION YARD.

AVERAGE TIMES FOR TYPICAL ONE WEEK PERIOD.

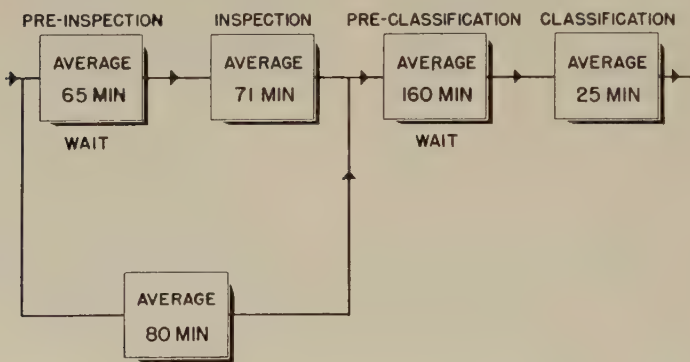
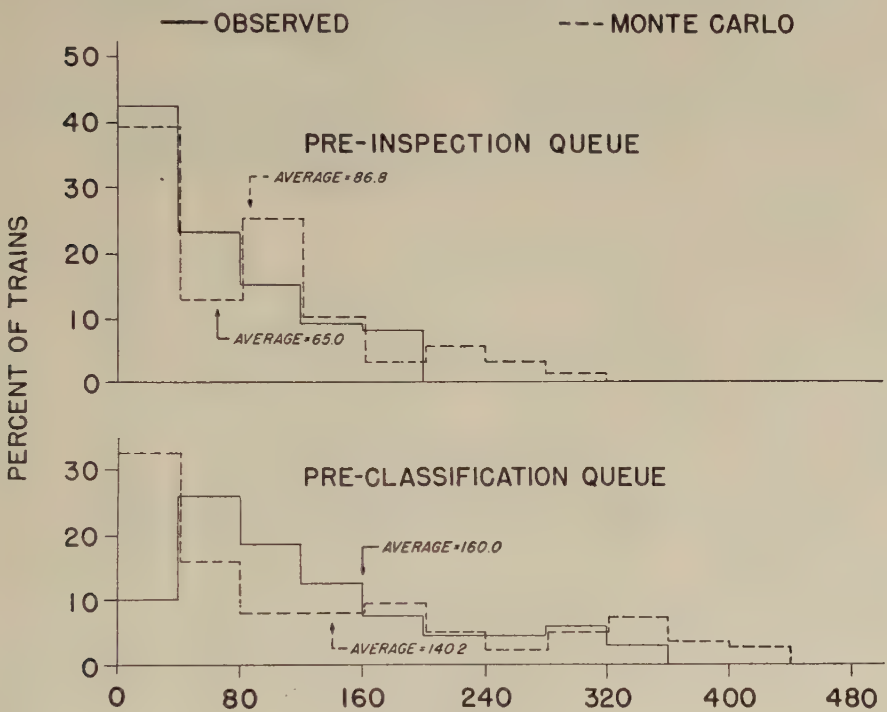


Fig. 3.

Histograms of the distribution of times the trains spend in the two queues are shown in fig. 4. In the pre-inspection queue, for example, about 43 % of the trains entering the yard wait between 0 and 40 min before inspection starts. This is shown by the solid line which was obtained from actual yard data. About 25 % of the trains wait between 40 and 80 min, and so on. The dotted line shows the results obtained from the application of the experimental, or Monte Carlo Method, to the simple yard model of fig. 3. The Monte Carlo results are irregular, just like

the yard data, since only a limited number of computational steps were used. Note that the experimental results (dotted line) follow the actual operation (solid line) rather well, except that in the pre-inspection queue it extends too far out on the time scale. And in the pre-classification queue it not the fluctuating situation and reassigns personnel and equipment in a continual effort to offset the undesirable effects of these fluctuations. If the general rules followed by the yard manager are known, we can express these as so-called *feedback* relations and include them in the Monte Carlo

DISTRIBUTION OF WAITING TIMES IN A CLASSIFICATION YARD.



WAITING TIME, MINUTES.

Fig. 4.

only extends too far out on the time scale, but it is also too high in the time interval 0 to 40 min.

The next step is to investigate the cause of the principal disagreements in fig. 4 between the Monte Carlo results and the yard. To this end, we note that the theory has so far not taken any account of the continual corrective actions of the yard manager. That is, he continually watches Method. Discussion with the yard manager indicated that the following rules essentially were used. When the number of trains in the pre-inspection queue is four or greater an extra inspection crew is assigned. When the number of trains waiting in the pre-classification queue is five or greater another hump engine and crew is added. When only one train is waiting to be classified, the hump engine will frequently stay

down in the bottom, and to reflect this, a rule was used in the computation which was that in 50 % of the cases where only one train was waiting it would be humped without delay, and 50 % of the time it would be kept waiting.

The result of applying the Monte Carlo technique, using these rules, is shown in fig. 5. Now there is considerably closer agreement between the observed data and the experiment in both pre-inspection and pre-classification. It will also be noticed that there is better agreement between corresponding average waiting times. Here the pre-inspection averages are 65 and 61 min for the actual and Monte Carlo results, and the pre-classification figures are 160 and 151 min. In both cases the difference is about 6 %.

The value of this procedure is that one can now study the effect of changes in various phases of the classification yard operation *on paper,* which avoids the risk of making premature changes in the yard itself. In the experiment one can change the processing rates, the length of the trains, the rate at which they arrive, and so on, and use the results to predict what would happen in actual yard operation if the corresponding changes were made there. Changes of this kind are frequently tried out in practice by those in charge of a railroad operation, and care is required to avoid disrupting the operation. We don't have to worry about that when we work on paper, and the cost of the experiment is trivial by comparison. In fact, if one had a continuing requirement for this sort

DISTRIBUTION OF WAITING TIMES IN A CLASSIFICATION YARD.

("FEEDBACK" APPLIED)

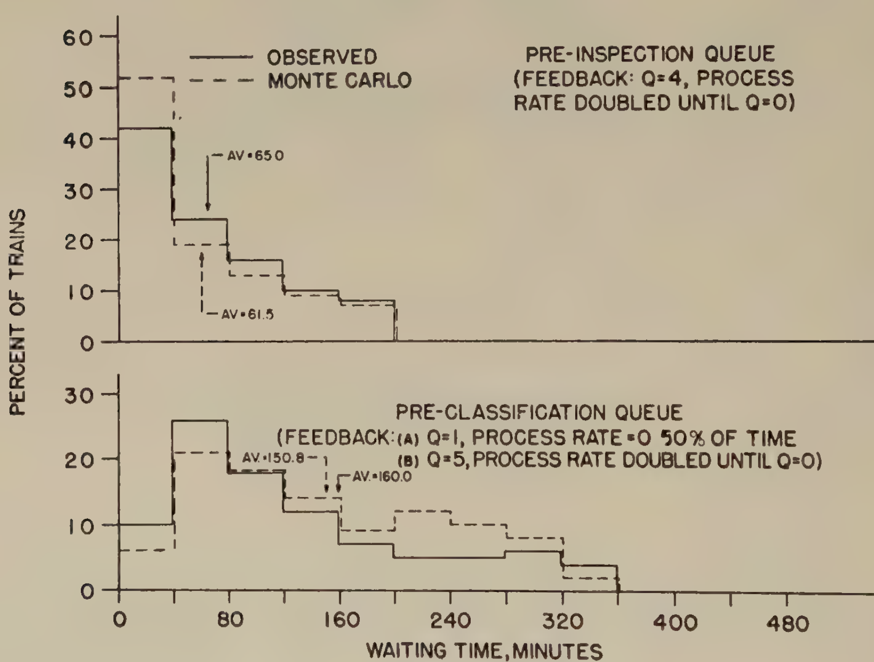


Fig. 5.

of computation, the whole job could be done on special computing equipment and in this way the equivalent of years of experience could be obtained in a matter of a few hours or days. The queueing theory is put to so many uses that it will not be long before such a computer exists. Some designs already have been proposed.

Case 3. — Application of failure theory to rail replacement.

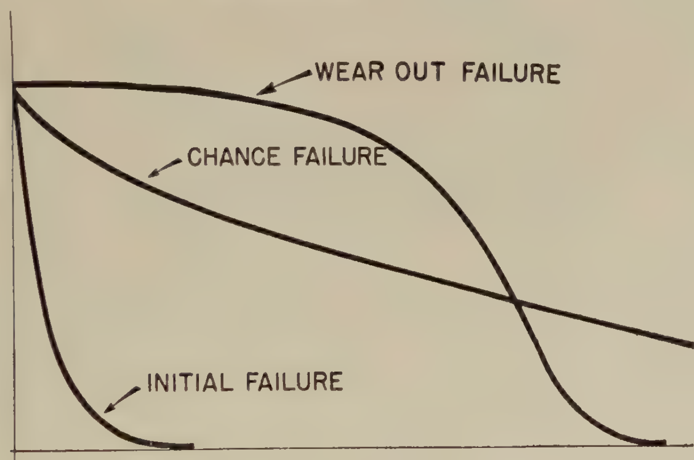
This case is concerned with the theory of failures. The theory of failures has a long history. It has been developed to a high degree by the insurance companies, and has more recently been applied by O. R. scientists to military and industrial maintenance-replacement problems.

There are three general types of failure. In most situations, one usually finds a mixture of these. The important point to understand about the theory of failures is that if one plots length of life data from three types of failure, he would obtain three distinct curves. These characteristic survival curves are shown in fig. 6, in which the percent of items surviving to any given time are plotted against time.

The uppermost curve in fig. 6 is characteristic of what is called wear out failure. One obtains this type of curve when the item in question is installed in good condition, and physically wears out from use or age. Not very many fail in the early states, and then after a while more and more fail until only a few especially long-lived cases are left.

Now it is also possible that the life-curve of a piece of equipment might appear like the middle curve in fig. 6. This is called a chance failure curve, since in this case any item is equally likely to fail at any time, independently of its age. If the failure of parts is found to occur according to this chance failure law, there is no advantage to be gained by expending funds in preventive maintenance on them. The parts die at the same rate, whether they have just been installed or have been in service for some time. Maintenance has no effect on the life, and hence both its cost and the lost equipment-time would be wasted.

MECHANISMS OF FAILURE.



TIME.

Fig. 6.

THE DEPENDENCE OF RAIL SURVIVAL ON TRAFFIC CARRIED.

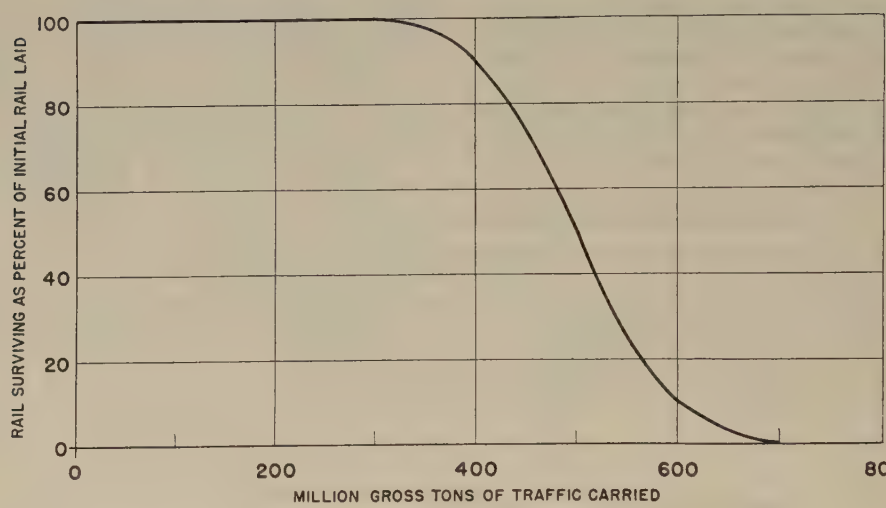


Fig. 7.

COST PER YEAR OF REPLACEMENT OF RAIL
ON THE BASIS OF TRAFFIC CARRIED.

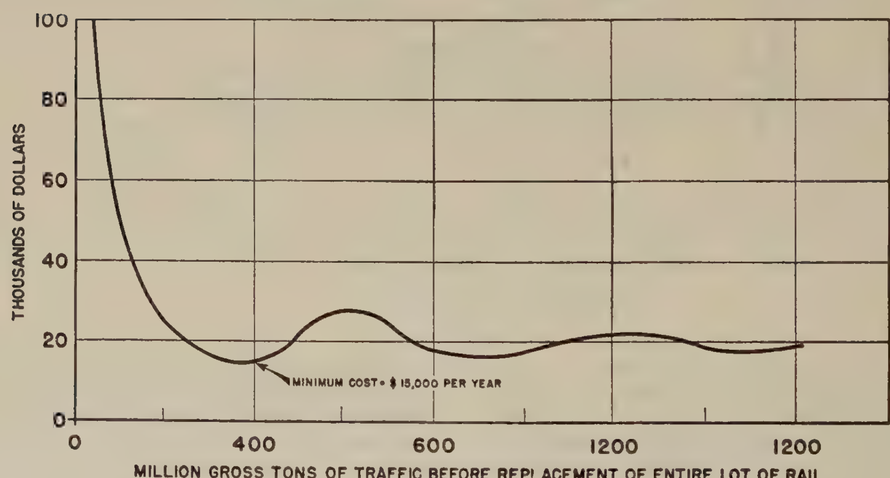


Fig. 8.

It was stated earlier that most equipment will exhibit a combination of the pure types of failure. For example, in a rail failure the grinding of the wheel rims and the flanges on the track are characteristics of wear out failure. An example of chance failure is found in the spinning of the locomotive driver wheels which produces

burns on the top of the rail. These latter occur more or less at random in time after a rail has been placed in service. They are not very important, relative to the overall picture, but they are there and have to be dealt with in a different way from wear out failure.

Finally, there is the type of failure called initial failure, characterized by the lower curve in fig. 6. It is common in operations of electronic equipment where failures often occur as soon as or very soon after the piece of equipment is turned on. In fact, new naval vessels, for example, are subjected to shakedown cruises, one purpose of which is to discover and rectify initial failures.

In this case, a lot consisting of 1 000 rails has just been installed. From the performance of other rail of the same type, a rail failure curve is obtained as shown in fig. 7. This curve shows the percent of the initial rail lot which must be replaced after a given total tonnage has passed over it. The density of traffic over this rail is 50 million gross tons (MGTs) per year. The cost of replacing rail in large lots, such as 1 000 or more, is \$ 100 per rail; the cost to replace rails one by one as they fail is \$ 200 per rail. The problem is to determine the procedure which should be followed in order to minimize the replacement cost.

The cost per year (equivalent to 50 MGT) of complete replacement of the lot of 1 000 rails at intervals of a given number of MGTs, starting with the original installation, is shown in fig. 8. The cost of replacing individual rails as they wear out prior to the complete replacement is included in the curve of fig. 8. This figure shows that the lowest annual cost results from the replacement of the entire lot of rail after 400 MGTs have passed over the road, although during this period approximately 10 %, or 100 individual rails, will have had to be replaced. The total cost of this procedure, spread over the 8 years required for 400 MGTs of traffic, is approximately \$ 15 000 yer year.

C. — ORGANIZING FOR RAILROAD RESEARCH.

Organizing for research requires the answers to several major questions. How much research should be done, what kind of people are needed to do it, how should the group fit into the existing railroad organization, and how should a railroad get such a group started ? Some remarks on these points are contained in the following paragraphs.

The functions of railroad research.

The two basic objectives of research in an industrial concern are to help in the development of new and improved products for the firm to sell and to help in the constant battle to reduce costs. Research assists in the development of new products in two ways. It is used to find out the needs of the prime consumers through well known techniques, such as market research. It assists the engineering departments, the sales department, and other groups within the firm in designing, creating and developing new products to satisfy these needs. This is done through scientific research in basic fields of physical science, such as, chemistry, physics, metallurgy, etc.

Research helps in reducing costs by helping to develop better materials, processes, and equipment designs. It may also help through commercial research in evaluating cost and price trends, long-range market trends, and so forth. Industrial research thus has two major divisions; research in the physical and natural sciences, and commercial research which studies the economic factors influencing the company's business.

The product of the railroads is transportation service. Hence, the objective of research by the railroads is to create new and improved transportation service. While conventional industrial research emphasizes technical research to produce new and improved equipment for these industries to sell, railroad research emphasizes the production of new and improved methods of providing transportation service.

Research by the railroads can produce improved railroad service and lower costs in two ways; first, by developing improved ways of carrying out this service using available equipment; second, by evaluating the requirements of the railroad industry for new equipment in the light of shipper requirements so that new types of transportation service may be possible.

Thus the functions of research in a railroad are :

1) to develop more effective methods of providing transportation service;

2) to develop requirements for new equipment which will improve this service;

3) to evaluate new equipment proposed or offered to railroads.

It has been stated that much of railroad « research » through the years has been carried out by the suppliers. This is very likely true of the technical research, although the recent establishment of a common railroad Research Center under the auspices of the Association of American Railroads is a major contribution in this field by the railroads. However, the functions listed above *do not* duplicate those of technical research. Rather, properly executed, they lead to supplementation of the technical research and can be of invaluable mutual assistance, providing a direction for technical research which will at the same time make this research more effective and provide a highly desirable incentive for more technical research by guaranteeing that a need exists for the results of this technical research.

The amount of research.

The amount of research carried on by industry has been the subject of a considerable number of studies of various government and research agencies (see, for example, the studies of the Harvard Business School summarized in the « Harvard Business Review » May-June 1954, and « Industrial Research and Development » January 1953, prepared by the Bureau of Labor Statistics of U. S. Dept. of Labor).

Table 1 summarizes some results of the Harvard study. This study included only technical or scientific research. It does not include the large sums of money spent by industry on commercial research.

The Bureau of Labor Statistics' study showed that industry spent nearly \$ 2 billion on technical research in 1951. The leaders, the electrical machinery industry and the aircraft industry, spent close to \$ 450 million, and \$ 420 million, respectively. Primary metals and fabricating industry spent less than \$ 100 million, and all non-manufacturing industry spent \$ 180 million — far less than electrical, aircraft, chemicals and motor vehicles. Of the 2 845 research laboratories in industry listed by the National Research Council, the railroads had 4 research laboratories.

One cannot fail to note that the two most dynamic and expanding industries, aeronautics and electrical, spend large sums on research, both absolutely and as a percentage of sales.

From Table 1, it would appear that a reasonable figure for research for the railroads might be about 1 % of revenue if the analogy between the railroads and other industries is to be carried over. Thus, a railroad having a gross revenue of \$ 100 million per year, for example, would spend 1 % of this amount, or about \$ 1 million per year. The larger U. S. railroads would spend more than this amount and the smaller railroads less, although, as indicated in Table 1, not in direct proportion to the revenue earned.

Further reference to Table 1 permits the expression of these research expenditures in terms of professional personnel. From Table 1, it appears that the cost per professional research worker is \$ 20 000, while the average for all research personnel is about \$ 8 400 for all research workers, including technicians, clerks, and other non-professional members. This figure includes all expenses other than plant. Thus, there would be about 50 professionals and over 100 research workers in a research department budgeted at \$ 1 million per year. For a research activity of this magnitude, salaries

TABLE 1. — **Highlights of the Harvard Business School study of industrial research.**

Items	*Percent of 4 800 Respondants Supporting Research*	*1952 Median Figures for 191 Leading Companies*			
		Percent Research to Sales	*Increase in Spending Over 1951*	*Dollars Spent per Research Worker*	*Percent Professional to all Research Workers*
All Firms	44	1.3	13	8 400	46
Industry					
Food and Kindred Products	31	0.3	8	8 300	46
Textile and Apparel	34	0.7	7	8 200	39
Furniture	27	0.5	9	6 500	19
Paper, Timber and Wood Products	28	0.7	15	7 100	49
Industrial	74	2.9	15	9 400	45
Drugs	59	4.9	12	9 600	46
Paints	72	1.7	8	6 800	52
Misc. Chemicals	69	2.4	9	7 700	39
Petroleum and Coal Products	40	0.7	14	9 000	43
Rubber	53	0.9	21	8 500	66
Stone, Clay and Glass	42	1.3	14	7 700	37
Primary Metal	43	0.9	11	8 500	40
Fabricated Metal	40	0.7	10	9 600	53
Machinery except Electrical	61	1.4	12	7 300	39
Electrical Machinery	71	2.7	17	8 200	44
Transportation Equipment	51	1.4	9	9 700	36
Laboratory Instruments	87	3.0	40	7 300	37
Mechanical Instruments	69	2.0	11	8 900	52
Other Professional, Scientific and Controlling Instruments	79	2.0	14	10 000	50
Size					
Less than 500 Employees	32	3.4	10	8 200	59
500— 2 000 »	80	2.0	16	8 100	49
2 000— 5 000 »	94	1.4	12	8 000	45
5 000— 7 000 »	96	1.2	12	8 200	50
7 000—10 000 »	97	1.5	13	8 500	46
10 000—Employees or more	99	0.8	14	8 700	41

would range from about $ 4 000 for junior professionals to over $ 20 000 for the directing scientist.

Organization.

One of two types of research organization are generally used in industry — a central or a decentralized research organization.

With a centralized organization, most of the research activities are concentrated in a central research department which then provides services to the other departments of the firm.

A research department of a railroad would function much the same way as any of the other supporting departments.

In the decentralized version of a research organization, a relatively small group is attached to the staff of the executive vice president or president, and similar smaller groups are attached to each of the major departments which may require research. The small group attached to the executive vice president's office is responsible for coordinating the research work throughout the organization, but each of the smaller research units reports directly to the respective department heads.

There are advantages and disadvantages for each of these organizational arrangements which make it virtually impossible to state dogmatically that one or the other is always the better. Two rules might be of some assistance in making a decision along these lines, however. First, a research group needs cross fertilization of ideas so that if the entire research effort which can reasonably be supported by an organization is fairly small, say less than 25 members, it probably would be desirable to have a central department. Second, if the individual departments of an organization are very dissimilar and require widely differing amounts of research, then the central department may also be desirable.

Personnel.

To carry out satisfactorily the functions described in preceding paragraphs, a wide variety of skills and capabilities are required of these research personnel. Because the major subject under study is the activity of the railroad, these personnel should be qualified in the scientific study of large-scale operations. They should have a clear understanding of scientific method and of advanced statistical procedures. They should be qualified in economics, have a broad knowledge of the industries served by the railroads, and a knowledge of market research and accounting practices. To be able to recognize new equipment requirements and to evaluate the proposals for new equipment, this group needs a certain number of technical skills. In general, these will result from training in the physical sciences and from training in electrical, electronic engineering, and mathematics, and other branches of engineering.

Many of the personnel required for a group such as this can be obtained from present railroad personnel, and some of this work is already being done in various departments of the railroads. If this is true, then why is it desirable to give this activity formal recognition by establishing a separate department ? It is desirable for the same reasons that it is desirable to establish any department — to emphasize a particular, important organizational activity, to give it direction from top management, and to guarantee that its work is facilitated and the results of the work employed in an expeditious and effective manner.

How to establish a research activity.

A railroad if it should elect to establish a research activity may do so in a number of ways, but perhaps the simplest approach is the direct approach of hiring a qualified director of research, or appointing a qualified member of the railroad to that post, and giving him the responsibility and authority to establish this activity.

Other procedures include utilizing, at least at the outset, the services of competent research institutions, or the outright purchase of a complete research activity.

It is likely that any procedure which a railroad might follow to establish a research activity would be a difficult one. Research activities in industry have been a long time getting established, and many problems still remain; furthermore, difficult as it is to obtain competent technical research personnel, it is even more difficult to obtain personnel competent in the special functions of railroad research. In view of these difficulties, a railroad which is seriously thinking of organizing an O. R. group would do well at the outset to engage competent help on a consulting basis to aid in the formulation of an O. R. program and the hiring of individuals to staff that program, as well as in helping to evaluate those personnel within the railroad who might be suitable for the O. R. team. One

last point is worth stressing. Research is a difficult function in any business organization. It takes time and patience, and above all the understanding support of top management. A management which expects results over night from an Operations Research Group is generally not ready to have one.

The future of operations research on the railroads.

The future of research on railroad operations is, in a sense, the future of the railroads themselves. For research by a large industry is like reflective thinking by an individual. An individual, who after some point in his life solves all new problems with which he is presented by « reaction », and then does not think about the solution again, is like the industry that lives only from day to day. He learns little and, therefore, changes little. It may be that, for some industries and for some individuals, the need for learning is over. It has been dramatically demonstrated, however, by the trucks and the air lines that the railroads' requirements for learning are not over. It is not enough for the railroads to provide just their present service, nor in fact, is it enough for the railroads to continue to improve this service at the rate which it has been improving for 20 to 30 years. This rate is not fast enough. The railroads have no alternative if they wish to remain healthy financially, but to take on all the characteristics of free enterprise, including full-scale research programs.

There is increasing interest in the railroads in research of all types. The AAR has established a Research Center and several railroads have research activities of various types. A number of railroads have long done O. R. and achieved remarkable success by this means. In addition, a number of new research institutions and universities have shown interest in the railroads.

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Report on sound control for railway buildings.

(*Reprinted from « American Railway Engineering Association* (AREA) », *Bulletin* No. 532, November 1956.)

Final report, submitted as information.

Introduction.

Sound control as it relates to buildings is a comparatively new technical field and is based on scientific principles and extensive research in the study of acoustics. From the studies and resulting test data many techniques and materials have been developed to solve sound-control problems. Much of the technical information is available in manufacturers' literature and in publications on standardized acoustic values of materials. The correct utilization of this technical data requires an understanding of acoustics and a working knowledge in the field of sound control. It is the purpose of this report to provide a general guide in planning and designing sound control for railway buildings and to give some background in the fundamentals of sound for the intelligent use of reference data on acoustics.

Sound-control problems can be very complex and involved, and an accurate analysis resulting in a satisfactory and economical solution may require an expert consultant in the field of acoustics. Sound control should be an integral part of the architectural problem, starting with the preliminary planning and continuing through the working drawings, to ascertain good acoustic conditions in the completed building at reasonable cost. Good planning is the first important noise-control measure. It will recognize acoustic problems in their relation to general functioning of the building and include site location and utilization, interrelation of horizontal and vertical spaces within a building, mechanical noise isolation and construction covering methods and materials.

Sound control is becoming increasingly important for reasons of health, comfort and efficiency, while the rapid growth of mechanization in offices has greatly increased the number and variety of noise problems. At the present time accepted standards of allowable noise have not been established for the industrial area. Some measures for control of noise can be considered in shop planning.

Generally, sound control deals principally with acoustics, the improvement of hearing conditions and the reduction of noise in rooms. Acoustic problems and their control measures are discussed in this report as a general approach by the nonacoustic trained railway engineer or architect. For a broader and detailed study of the physics of sound and architectural acoustics, a bibliography is included at the end of this report. This bibliography also contains the reference sources for material on this assignment.

Locations for sound control.

Many business and industrial organizations recognize that the comfort and health of their employees are matters of great importance from the standpoint of increased output as well as furthering friendly relations between management and employees. When sound-control treatment has been installed, an improvement in efficiency of the employee can be expected. Test installations show that more time is required to do a given amount of work in a noisy room than in a quiet one. While proper sound-control treatment often represents a considerable investment, it can increase efficiency, reduce errors and contribute to the contentment and health of workers. The acoustic treatment of spaces used by the

traveling public can be effective and favorable to good hearing and comfort. In a station waiting room, ticket office or other passenger facility, the outside noises are often at a high level, but with properly adapted sound control, the intensity of the noises can be reduced substantially to furnish the traveler a quiet, comfortable environment during waiting periods or when in the course of making arrangements for travel.

Modern buildings and business office methods use mechanical equipment of many kinds to save time and effort in comfortable and pleasant surroundings. While elevators, heating and cooling systems, communication systems, office and business machines and equipment supply these needs, they also create a problem of sound control because of the noise created and the vibrations generated by the motors, fans, compressors and other equipment. The continuing rise in noise levels requires that more attention be given this problem in the design and functioning of buildings. There also appears to be a greater consciousness of noise in some areas that can contribute to the problem to make acoustic treatment a necessity for the contentment and health of workers.

There are many interior building areas in railway facilities, or related to railways in some manner, where sound control is commonly applied. There are some railway buildings and rooms not generally recognized as needing acoustic treatment. To carry on the functions of these facilities in the proper acoustical environment, the following list of noise levels in decibels is recommended based on intensities and frequencies ordinarily encountered when a difference of at least one decibel in the intensity level is required to produce a noticeable change in loudness under the most favorable listening conditions :

	Decibels.
Studios for recording, radio and television	25 to 30
Music rooms	30 to 35
Hospitals, auditoriums, motion picture theaters, lecture rooms, class rooms	35 to 40
Conference rooms, executive offices, directors rooms, small offices, employee meeting and club rooms	35 to 45
Private offices, drafting rooms and libraries	40 to 45
Telegraph offices, dispatchers offices, yard control rooms, telephone switchboard rooms	45 to 50
Large general offices, ticket offices, freight offices, yard offices, waiting rooms, stores, banks, lounges, etc.	45 to 55
Business machine offices, stenographic pool offices, duplicating machine rooms, print shops, restaurants, shop offices, store rooms, passenger concourse	50 to 55

In shops, boiler rooms, garages and other locations the noise levels are often in excess of 50 db, and range as high as 100 db. These industrial areas do not conform to any accepted standard and must be analyzed individually for design along practical and economical limits.

The sound intensity level can be measured by a sound-level meter. This is a device consisting essentially of a microphone or transmitter, amplifier, electrical network, variable attenuator and a meter calibrated to read the intensity level of the sound in decibels.

Divisions of sound control.

The divisions of sound control are basically three in number, consisting of (1) noise quieting, (2) audition, and (3) noise isolation. Most problems in sound control involve the first two of these in varying degrees which are generally classified together as acoustics of room interiors. Noise

isolation is an entirely different problem from the first two divisions and concerns the measures to confine high-level noises and vibrations to restricted areas. This problem arises in connection with mechanical equipment in buildings and business office functions, such as typing pools and business machine procedures.

1. *Noise quieting.*

Noise quieting is technically referred to as the reduction of the noise level and deals with the absorption of unwanted noise to provide a satisfactory acoustical environment. Research has disclosed that if noise energy is absorbed as rapidly as it is produced, preventing its reinforcement and accumulation, the disturbing intensity can be eliminated. Sound-absorbing materials on walls and ceilings of rooms offer the solution to the airborne sound problem. Noise quieting is the principal factor for treatment in offices, class rooms, hospitals, libraries and other interiors where protection against noise is required. Noise quieting does not provide for the preservation of the character of a sound as produced, and is the treatment provided where audition is not important.

2. *Audition.*

The other major factor in acoustics is audition, which considers good hearing conditions in auditoriums, theaters, conference rooms, music rooms and other interiors where sounds by the voice or of music must be heard to the best advantage. The treatment deals with the elimination of echoes, excessive reverberation and extraneous sounds. Audition can often be effected with sound-absorbing materials applied to the reflecting surfaces, such as the walls and ceilings, but the architectural design of the room is the most important factor in providing good hearing conditions. Proportions of the room relating to length, width and height, curving surfaces, angles, corners and decorative treatment must be studied for best acoustic results. The sounds must be distributed properly throughout the room for acoustic uniformity and to avoid disturbing echoes, undue focusing or isolated areas of low intensity of sound.

3. *Noise isolation.*

Sound control provides for the isolation of noise as an important aspect to be considered in the plan and design stages which are the basic means of providing satisfactory sound conditions in regard to both acoustics and structural vibrations. When the noise is of great intensity, the problem is usually one of sound isolation and the control of sound transmission and vibration to effect a reduction in the passage of sound and vibrations from one area to another. Little improvement results by making a room acoustically correct if there are noises entering from an adjoining area. Outside interference must be reduced to a very low level, and acoustic materials alone may not be able to accomplish this to the point where it would not be troublesome. Effective means of vibration control may need to be coupled with sound-absorbing materials to accomplish the desired condition.

Sound penetrates a partition through crevices and cracks and may also set the wall itself in vibration. Doors must be tight or of a special soundproof type with adequate seals. The amount of sound transmitted through a single wall, floor or ceiling by vibration per square foot is roughly inversely proportional to its weight. The lighter the material the greater is the sound transmission, a factor which must be considered with modern structural design employing materials of maximum strength consistent with lowest economic weight. Metal partitions with 3-in sound-absorbing filler have been found effective in general use for offices. Double walls separated by an air space or by materials differing considerably in density generally can effectively isolate sound. Lightweight concrete-block cavity walls can be used for this purpose. The double wall method takes up floor space and can create structural problems. Its efficiency is reduced if through connections are used. Another method is based on the erection of lightweight interior walls

which are within yet completely separated from the rest of the structure by shock-absorbing isolators. No solid, through connections are used. The isolators are installed at specific points to dissipate the sound impulse energy in resilient insulating material which constitutes a barrier between the course of the sound and the structure.

Effective ways to avoid noise generation in mechanical equipment is through careful designing, manufacturing and testing, but when the best possible mechanical job has been done, then the problem is one of air-borne sound or vibrations or both. This applies particularly to quieting ventilating and air-conditioning equipment made more complex when air ducts are used. The equipment should be designed and mounted to prevent the escape of operating noises, and the ducts should be treated to absorb sounds which might otherwise be carried to various parts of the building through the system.

Fundamentals of acoustics.

Research in the field of acoustics indicates that poor hearing conditions result from reverberation, the presence of sound after the source has ceased. This condition is caused by excessive sound reflections from walls and ceilings. The resulting reverberations do not permit the listener to distinguish successive words or sounds as definite and separate elements. Irritations, confusion and lack of intelligibility result. Excessive sound reflections are also the cause for much of the noise in rooms. Through the use of certain building materials, sound waves can be satisfactorily absorbed, and excessive reflections eliminated.

Knowledge of the fundamentals of acoustics is a necessary background to design properly a treatment for sound control. Sound waves and the energy they contain when generated in a closed room should be understood. The shape, size and construction of a room have a direct bearing on the acoustics because the sound waves and rays are affected differently under various conditions.

Sound can be defined as a wave motion in air. The waves are originated by any vibrating body and are audible if they rate at least 12 to 15 per sec. Shrill tones will vibrate up to about 20 000 per sec, beyond which they are not audible to people. The speed of travel of sound waves is constant, disregarding variations with temperatures, and is approximately 1 120 ft. per sec. Sound does not travel instantaneously and results in one of the most frequent causes of poor hearing conditions. Noise is made up of sounds, each varying in pitch and intensity, with character and volume determining the degree of irritation to persons exposed to it.

The sound wave can be measured in units called the wave length. A sound wave has intensity measured as the amount of energy contained in the vibrating air particles. The loudness measured in decibels depends on intensity, the greater the intensity the louder is the sound. Acoustic standardization has arbitrarily assigned 10-16 *w* per sq. cm. to correspond to 0 decibels as a reference value establishing an absolute sound-intensity level. The unit used for denoting sound intensity is the decibel, abbreviated db. One decibel corresponds roughly to the slightest change in the loudness that can be distinguished by the human ear for normal intensities and frequencies.

Any material will absorb varying amounts of sound for different frequencies. Absorption for a square foot of material may be only 0.12 units at 125 cps, 0.25 units at 250 cps, 0.88 units at 500 cps, and 0.77 units at 2 000 cps. From this it is obvious that the reverberation of a given room will depend upon the pitch of the sound. It is common practice to use a frequency of 500 c as that basis of comparison with other materials. This frequency is used in calculations for ordinary correction because it happens to be fairly accurate for general performance. For ordinary auditorium correction the 500-c frequency may be used. Radio and television studios and concert halls would need to be figured for other frequencies. For noise quieting in hospitals,

banks, offices and corridors, the average value of coefficients from 250 to 2 000 c, incl., should be used. This average value is known as the noise reduction coefficient, abbreviated as NRC.

Since sound waves can be transmitted, reflected or absorbed when sound encounters a barrier, such as a wall, all three actions occur to varying degrees. The absorptivity of the wall surface is generally recognized to be the percentage of incident sound energy not reflected, which includes sound transmitted through the wall in addition to the sound actually absorbed by the wall. The wave length of sound is not always small compared to conventional objects, so calculation of the absorption of sound by different types and shapes of materials is not a simple problem in geometry. However, the geometrical method is commonly used because it is simple and still sufficiently accurate. This method assumes an open window to transmit all of the sound reaching it and is described as having an absorptivity of 1.00. Absorptivities of materials, depending upon how well they absorb incident sound, classify 0.20 as moderate, 0.50 as good and 0.80 as excellent. An average person has an absorptivity of 4.5, varying only slightly with the manner of dress. This absorptivity is four and one-half as much sound as the hypothetical window will absorp. A material absorbing half the sound that falls upon its surface would have an absorption coefficient of 0.50, or 1/2 unit per sq. ft.

When a reflected sound reaches a listener with a time delay after the direct sound, it is called an echo. To be apparent this time delay must be at least 1/20 of a second. Reflections of sounds from the walls of a room generally occur so rapidly and frequently that no echo is apparent, but the reflected sound adds to the apparent loudness of the direct sound. After the direct sound stops, the reflections continue which causes the sound to persist at a gradually decreasing level until completely absorbed. Such prolongation of sound is called reverberation. The reverberation time is a measure of the prolongation of sound in a room after the source has stopped, also the time required for the sound to decay 60 db. The reverberation time depends only on size of the room and its sound absorbing qualities and not on power of the source or steady intensity. Some reverberation is desirable because it adds to the apparent loudness of the sound, and for many types of musical sound, reverberations seem to be desirable aesthetically. Excessive reverberation will cause overlapping and confusion of spoken syllables and musical tones, making hearing unsatisfactory. A general guide for reverberation time can be given in this manner :

Reverberation time.	*Hearing conditions.*
Over 3 sec	Poor
2 to 3 sec	Fair
1 to 2 sec	Good

The reverberation time of a room can be calculated approximately from the formula :

$$t = \frac{0.05\ V}{A}$$

where t is reverberation time in seconds, V is room volume in cubic feet, and A is the total absorption of the interior surfaces of the room. A is calculated by multiplying each surface area by its absorptivity and adding all of the absorption together. The constant, 0.05, depends upon room shape, but varies so little for conventional rooms and auditoriums that the single value is nearly always used. Most available data are based on this simple formula by W. C. Sabine, a pioneer in the field of acoustics.

The following simplified example illustrates the use of the reverberation formula for the calculation of reverberation time (t) at an assumed single frequency of 500 cps :

Room size by 100 ft., with 10 ft. floor to ceiling; Volume = 20 000 cu. ft.

Surface	*Absorption Coefficient*	*Area Sq.–Ft.*	*Absorption*
Floor—hardwood	0.03	2000	60
Ceiling—plaster on lath	0.03	2000	60
Walls—plaster on masonry	0.025	2400	60
Number of persons—20	4.3	......	86
			266 units

$$t = \frac{0.05\ (20\,000)}{266} = 3.75 \text{ sec.}$$

If this room is an office or other area where normal conversation is desired, a reverberation time of 3.75 would be classed as poor. Acoustic treatment of the ceiling would change the absorption coefficient to 0.75 if 3/4 in. thick perforated acoustic tile was substituted for the coefficient 0.03 for plaster on lath. Total absorption would then amount to 1 686 units and reverberation time, *t*, in the formula, would be 0.59 sec, which would be too low for good audition, but good for sound quieting and adequate for an average business office. The example shows relative abilities for absorbing sound of different types of material. These absorption coefficients with other details are found in the publication of the Acoustical Materials Association on « Sound Absorption Coefficients of Architectural Materials », as well as in other publications and manufacturers' catalogs devoted to acoustics.

Reverberation control does not always require that special acoustic materials be used. In moderate sized rooms where the volume per person is small, with wood paneled walls, upholstered furniture, carpeted floors, or curtained windows, the desired reverberation time may already be achieved.

Acoustic treatment.

Although the distribution of sound in a room is determined principally by its overall shape and smaller surface variations, the amounts and locations of absorbing materials also influence sound distribution. Generally, it is easy to get between 5 and 10 db of noise reduction by absorptive treatment. The results are often much greater than the noise reduction calculation indicates. Absorptive treatment on the ceiling or walls reduces the spreading of the sound and makes the room more like the outdoors where sound diminishes with distance from the source instead of being uniform everywhere. This reduction in the reverberation has a good effect on people, particularly in large rooms used for general work purposes.

A common treatment is to apply acoustic materials over the entire ceiling, but this may not be the right method where good hearing conditions are important. Complete ceiling treatments are satisfactory for offices and work areas where installation is for noise quieting only. The ceiling surface can be the most helpful in providing useful reflections between speaker and listener, but with acoustic treatment more material is used than is needed for reverberation control, making the room too « dead » for ideal hearing conditions of voice or music. Generally, sound-absorbing materials for reverberation control should be located around the perimeter of the ceiling, on upper wall areas and on other special areas of trouble. The wall opposite a speaker is an especially important location for echo control. Often only upper wall surfaces need to be treated with acoustic materials with nothing placed on the ceil

ing, or else only a small band of material on the ceiling near the windows. An auditorium should not have acoustic material on the middle portion of the ceiling if it is flat, as this area is helpful to the intensity of the speaker's voice for those in the rear. Placement of acoustic materials is important for the best hearing conditions and often calls for special architectural designing, more so than covering an entire ceiling.

Based on broad experience it has been noted that the total units of absorption in a room, not including absorption by occupants, should range between 20 and 50 % of the total interior surface area. The 20 % limit will require acoustic treatment of the entire ceiling, or its equivalent, and the 50 % limit will require treating the entire ceiling and over half of the wall areas. Generally, the smaller percentage is required for rooms of large floor areas in comparison to the ceiling height and for sound sources of medium intensity and wide spacing. The opposite conditions require use of a larger percentage of the range for good results. Where there may be some doubt in the planning of new construction as to the type and distribution of noise sources, or if the area is subject to change, then an amount of absorption material in the upper range will provide the widest area of control.

The range of absorption between 20 and 50 % is important, but in providing acoustic correction for an existing noisy area, it is also necessary to escertain that the added absorption will produce an improvement. The change in absorption is measured by the absorption ratio of the new condition compared to the old. It has been observed that to make a satisfactory improvement in an area, the total absorption of all the materials in the room after correction should be in the range of 3 to 10 times the absorption of all materials in the room before correction. The ratio of 3 is about the smallest that can be detected by ear under average conditions. The ratio of 10 in an average room is the maximum economical limit for absorption beyond which reducing reflection is not likely to be heard.

The ratio of new and old absorption totals of a room denote loudness or intensity reduction and can be expressed in decibels of reduction of reflected sound energy by the formula :

$$R = 10 \log \frac{A_2}{A_1}$$

Where R is the reduction of reflected sound energy measured in decibels, A_2 is the total absorption of materials in the room after treatment, and A_1 is the total of absorption of materials in the room before treatment.

In the example showing calculations for reverberation for a room 20 by 100 ft. with 10-ft. ceiling height, the ratio of new absorption materials to the old equals 6.34, which falls in the middle of the recommended range of 3 to 10. Applying the formula for R shows 8.02 db improvement by the application of the ceiling tile. If this office had a number of noisy business machines in use, additional acoustic material applied to the walls would be desirable to effect a greater reduction of reflected sound.

In a room with large window areas, the wall area may be insufficient for application of acoustic material to get the required reverberation time. Acoustic baffles made of absorbing materials suspended away from the walls may be used to make up the shortage. In a shop with baffles placed around a machine so as to partially enclose it, the sound is absorbed at the source before it has a chance to spread to other parts where a lower sound level may be desired.

Baffles to be effective must be very highly sound absorbent, and this can be done by using 3 to 6-in layers of porous materials. Mineral wool, glass wool or other fibrous materials can be used when encased within perforated metal or perforated asbestos board coverings. Highly porous masonry can also be constructed as effective baffles.

Selection of acoustic material.

There are many acoustic materials available with many varying features to be considered. Noise quieting efficiency is of prime importance, but selection should not be made on this characteristic alone. The conditions peculiar to the particular job or area to be treated are important. Physical characteristics of different acoustic materials, the manner of application, and costs must be considered with each installation best to meet the architectural as well as the sound control problems.

1. *Coefficients.*

The coefficients of absorption indicate the percentage of sound absorbed at different frequencies from 125 to 4 000 cps. The coefficient also varies with the thickness of the material, size of pores, and ratio of pore volume to total volume.

2. *Noise reduction coefficients.*

The noise reduction coefficient (NRC) is the average for the 4 middle frequencies from 250 to 2 000 cycles, incl. Minor differences in NRC values are not important as a difference of less than 10 points is seldom detectable in the treated room. In specifying for sound treatment, it is best to provide a range of 10 cycles in the NRC for the type of material to be used.

3. *Relative costs.*

The cost of an acoustic treatment is determined by the initial cost of the acoustical material, the manner of mounting and the backing. The type of material, mounting and backing are frequently established from local building code requirements. It is to be noted that the cost of the material is not in relation to the efficiency, but to the method of manufacture and composition of the material.

Perforated fiber-type tile is a low-cost material with a high sound absorption.

Mineral-type tile and glass-fiber-type tile are comparable in price and next higher in cost.

This is followed in cost by tiles of pure cork material which are available for special uses in locations where the humidity is very high.

The metal pan unit with a mineral wool pad is highest in cost of material.

Installation methods affect the cost and are often determined by job conditions. Cementing to an existing plaster backing is generally the most economical method.

Concealed nailing to wood stripping is economical, but depends upon acceptance under local building requirements.

Mechanical suspension systems with the tile set in metal splines are often higher than other systems, but can be used to advantage to conceal overhead piping, ducts and conduits as well as making these facilities available by easy access through removability of any of the tile.

Acoustic plasters and plastics are about the same in cost. The two additional coats of acoustic material required cost more than fiber tile on a base coat of plaster.

Blown-on acoustic plaster is probably a little less in cost than trowelled acoustic plaster, but job conditions will have a bearing on the cost.

4. *Resistance to fire.*

Fire resistance is an important consideration in safeguarding lives and property, but there is some difference in opinion regarding the importance of acoustic material as a noncombustible material. It may be considered one of the interior finishes in buildings where the structure itself provides a large measure of fire safety, and as such would not need to be noncombustible.

Building codes may require noncombustibility, and generally the mineral tiles are noncombustible. The fiber tiles are usually classed as slow burning or combustible. These slow burning or combustible tiles are permitted in some codes if the backing is solid and fire resistant, such as plaster without the finish coat, or a sheathing of gypsum board.

5. *Rodent, vermin, termite, mildew, dry-rot resistance.*

No food for rats, mice or other pests should be contained in the material which might invite attack for itself alone. Most acoustic materials meet this requirement but do not qualify as barriers as well as wood or plaster.

Some locations may require protection against mold, mildew, decay, dry rot and termites. This extra protection is offered in acoustic materials treated with pentachlorophenol preservative.

6. *Light reflection.*

The light reflection value of a ceiling is important for proper lighting in the room as well as for economy of lighting cost. This value is now given by most producers. It has been common practice to use white or off-white colors for tiles which give a high reflection of light. Some manufacturers treat the bevels of tiles with the same surface finish, which increases the light reflection value over those that permit the untreated material to be exposed. In using colored tiles of brown, green, gray and yellow, allowance for lower light reflection should be made.

7. *Heat transmission.*

Some acoustic materials, such as cork, can adequately serve the dual purpose of acoustic correction and thermal insulation. This factor is not generally furnished in manufacturers' data, but is available on request to the producer.

8. *Weight.*

The weights of acoustic materials vary greatly from fiber types to mineral types, ranging from 0.10 to 2.30 lb. per sq. ft. The weight of the material may have some effect on the type of suspension system and in the structural considerations of the building.

9. *Moisture.*

In areas where humidity is excessive, like kitchens and washrooms, the moisture can be destructive to many acoustic materials. A 100 % cork material has a high resistance to moisture and is suited to an environment where humidity is high.

10. *Effectiveness, paintability and maintenance.*

Architectural acoustic tile has been slotted, perforated, fissured or otherwise provided with small apertures in the materials to increase absorption coefficients. Diameter, depth and distribution of the apertures over the surface of the absorbent greatly affect the sound-absorbing efficiency. The scientific explanations for these variations are not completely understood. Covering such a material with a thin perforated screen of metal or other hard material does not interfere measurably with its sound-absorbing efficiency. With as little as 10 % of the screen perforated, practically all of the sound energy will be transmitted to the absorbent material backing. This important characteristic makes possible the painting of such materials with a negligible decrease in the absorbing effectiveness while observing the precaution of not clogging the perforations, slots or fissures.

These materials can generally be brushed, vacuumed or washed satisfactorily. When brushing or vacuum cleaning is not adequate, a more thorough cleaning may be done by washing with mild soap and water applied with a moist cloth or sponge. Water paints should not be used, as they have a tendency to warp some acoustic materials. Some staining, such as that from heating and cooling registers, smoke and other causes, are difficult to remove and may require painting. Aging also causes discoloration not easily removed that can be covered with repeated coats of paints without harm to the original effectiveness of the material.

Metal-pan-type tile with a blanket of mineral or glass wool provides an easily maintained, washed or brushed surface.

Perforated mineral board of hardboard surfaces are also washable. This type of treatment is very efficient and is particularly well adapted near the floor level on walls such as in business machine rooms where a high degree of sound control is required. The hard surfaces are not so easily damaged and are easily maintained. A 4-in. paint brush is recommended for applying soapy water to metal pan units followed immediately by an almost dry sponge to avoid wetting the sound-absorbing pad backing.

Acoustic plaster and plastics.

Acoustic plaster has been in common use as a decorative sound-absorbing material that eliminates the mechanical appearance of some other treatments. It is a trowelled-on efficient material with adaptability on flat or curved surfaces and architecturally flexible for intricate designs. The results obtained vary considerably with methods employed in the installation. The material is generally tinted before application when some coloring is desired, as painting impairs the absorbing efficiency. Several prepared spray paints have been advanced for maintenance painting, but there is no assurance that efficiency will not be damaged. Spray painting can be used only in a few locations, while brush painting will impair effectiveness. The nature of acoustic plaster, its application and finish are variable factors in each installation that do not assure a high initial effectiveness nor give assurance of long-lasting absorbing qualities. Acoustic plasters that have been perforated with nail holes after the material has received finish trowelling suffer less in loss of effectiveness in repainting.

Acoustic plastic is a trowelled-on material of mineral composition with qualities similar to those of acoustic plasters. A sprayed-on material with asbestos fibers is also available for which claims are made by the manufacturer for absorption by tiny pores and a surface that yields with sound waves and reduces their intensity through diaphragmatic action. It is recommended for both acoustic and thermal purposes and is adaptable to the underside of roofs, metal buildings, corrugated cement asbestos buildings, boiler rooms and other rooms where temperature control is important. These types of material must be applied properly and have sufficient binder to prevent shedding of fibers.

Concrete masonry.

Sound treatment can be achieved with sound-absorbing concrete masonry for both quieting and sound transmission from room to room. For economy of construction concrete-block surfaces are being used in building interior finishes. By omitting plaster finishes, the textured surface is exposed and serves well for noise quieting even when painted.

For both noise quieting and soundproofing, cavity walls using concrete block are very effective, absorbing up to 55 % of sound striking it and reducing sound transmission through the wall as much as 55 dbs. This method is recommended when architectural design and cost will permit for such rooms as television and radio studios, auditoriums, theaters and classrooms.

Technical data and information on acoustics.

The technical data and information necessary to select the acoustic material required in a design for acoustic treatment is available in manufacturers' catalogs. Much of this information has been combined in one publication by the producers of architectural acoustic materials who have formed The Acoustical Materials Association for the purpose of furnishing engineers and architects technical data on sound-absorbing materials. Their Bulletin XVI-1956 on « Sound Absorption Coefficients of Architectural Materials » classifies these materials and provides technical information pertinent to the selection and design of an acoustic treatment. From the tables the available materials can be selected readily to meet certain requirements of appearance, composition, method of installation and acoustic efficiency. The materials

available are classified in the following groups :

1. Regularly perforated cellulose fiber tile;
2. Random-perforated cellulose fiber tile;
3. Slotted cellulose fiber tile;
4. Textured or fissured cellulose tile;
5. Perforated mineral fiber tile;
6. Fissured mineral fiber tile;
7. Textured or smooth mineral fiber tile;
8. Membrane-faced mineral fiber tile or board;
9. Perforated metal pans with mineral fiber pads;
10. Perforated asbestos board panels with mineral fiber pads;
11. Sound-absorbent duct lining;
12. Special acoustic panels and systems.

For technical data on acoustic plaster and plastics, masonry materials, structural metal panels and other materials for sound control, reference should be made to the catalogs of producers of the material. It is also possible to attain variations in absorption of sound at particular frequencies by using wood, metals, masonry products and fabrics in attractive finishes. Upholstered seating provides almost the equal number of adsorption units that a person furnishes. This is an important consideration when figuring a treatment independent of the number of occupants of the room.

From the bibliography that concludes this report can be found complete tables of coefficients of the many materials that are used for interior finish of rooms. A list is furnished here of a few materials commonly used in simple calculations for reverberations :

Material	*Coefficients*		
	125 CPS	*500 CPS*	*2 000 CPS*
Brickwall, unpainted	0.024	0.03	0.049
Brickwall, painted	0.012	0.017	0.023
Floors :			
Concrete or terrazzo.	0.01	0.015	0.02
Wood	0.05	0.03	0.03
Linoleum, asphalt tile, rubber or cork tile on concrete		0.03–0.08	
Carpet, without pad	0.09	0.20	0.27
Carpet, with felt pad	0.11	0.37	0.27
Glass	0.035	0.027	0.02
Marble or glazed tile	0.01	0.01	0.015
Plaster, gypsum or lime, smooth finish on tile or brick .	0.013	0.025	0.04
Plaster, gypsum or lime, smooth finish lath	0.02	0.03	0.04
Plaster, gypsum or lime, rough finish on lath	0.039	0.06	0.054
Wood wall panels	0.08	0.06	0.06
Furnishings and Audience			
Fabrics, hung straight :			
Light, 10 oz per sq yd	0.04	0.11	0.30
Medium, 14 oz per sq yd	0.06	0.13	0.40
Heavy, draped, 18 oz per sq yd	0.10	0.50	0.82
Chairs, metal or wood.	0.15	0.17	0.20
Theater and auditorium chairs :			
Wood veneer seat and back		0.25	
Upholstered in leatherette		1.6	
Heavily upholstered in plush or mohair		2.6–3.0	
Audience, seated, depending upon kind of seats, apparel, etc.	1.0-2.0	3.0–4.3	3.5-6.0

Technical data and information on noise isolation.

The transmission of noise through walls, floors and ceilings takes place as a diaphragmatic vibration. The surface is set into vibration by either direct physical impact, called impact transmission, or by alternating air pressure due to sound waves, called airborne transmission.

The efficiency of a wall, floor or ceiling construction for sound insulation is known as transmission loss (T. L.) measured in decibels. It is the number of decibels a sound loses in passing through a wall. If a sound of 60 db intensity passes through a partition having a transmission loss of 20 db, it will have on the other side of the partition the difference between these two levels, or 40 db.

Transmission loss is a physical characteristic of a wall dependent on the materials and construction. Loudness of sound striking a wall, its size or the acoustic properties of the rooms on either side of it have no direct bearing on transmission loss, although it does vary with frequency of the sound. Generally, partitions and floors are more efficient at high frequencies than for low-frequency sounds. This is why ordinary conversation is sometimes heard through a partition as a low mumble caused by highpitched overtones of the speech sound, on which intelligibility depends, not being transmitted effectively. Tests on the transmission of speech through walls of known efficiency can be classified, assuming a noise level of about 30 db on the listening side :

Transmission Loss of Wall	*Hearing Conditions*	*Rating*
30 db	Normal, talking is easily understood through the wall.	Poor
30 to 35 db	Loud talking is understood. Normal talking is not easily understood.	Fair
35 to 40 db	Loud talking is not intelligible. Normal talking is heard faintly.	Good
40 to 45 db	Loud talking is heard faintly. Normal talking is inaudible.	Very Good
45 db or greater	Very loud sounds heard faintly or not at all. Example, radio at full volume.	Excellent

Placing a door or window having a low transmission loss in a wall of high efficiency will reduce the effective transmission loss of the wall. Cracks around openings or any holes will reduce the efficiency of a wall unless sealed by felt or rubber gaskets. Ordinary doors have a sound reduction of about 25 db. If more is required, a double door vestibule will help, or a special sound insulating door should be used.

Sound insulation of windows is not often required other than for those used for observation in radio and television studios. These should be double or triple in thickness of heavy glass, with each pane isolated from the frame by rubber or felt gaskets. Panes of different thickness are helpful in avoiding resonance effects.

Sound-insulating efficiencies of various partitions and floors at frequencies cover-

ing the audible range have been tabulated by various manufacturers who offer their engineering services for the proper application and use of their materials and designs.

A common occurrence requiring noise isolation concerns machines and the vibrations they create in buildings. Floors on which machines are located will be set into vibration which will generate sound waves in another part of the building. Steel framework will conduct vibration to create audible sound in areas far removed from the machine causing the vibrations. The sound created might be at an inaudible frequency, but still cause rattling of light fixtures, metal filing cabinets or other furnishings. The usual method for reducing the transmission of machine vibration is to provide a resilient mounting for the machine to curb and absorb vibration. Most commonly used materials for mountings are rubber, fiber board, cork and steel springs.

Machine vibrations are generally absorbed successfully by resilient materials, but the total load per square inch should be distributed over an area so that the load bearing of the material used will not be exceeded. Isolating efficiency of the pad is improved by additional thickness, but the load limit of the material is not changed.

Steel springs are frequently used to reduce transmission of vibration through a building but often tend to cause more vibration of the mounted machine. They can be used effectively under many and varying conditions, but must be carefully selected for each installation. The steel coil springs are designed for stiffness and load limit and are used for hangers as well as direct load bearing. Isolators using rubber bonded to steel fasteners are also available for reducing vibration from machines. These units should be used only under conditions for which they are recommended by the manufacturers.

The problem of noise in passages where free movement of air is necessary, as in a ventilating system for a building, is very important. Acoustic absorbing materials installed under special conditions will reduce noise without noticeably impeding the air movement.

There are several methods of doing this, with the design depending upon the structure and factors such as type and thickness of sound-absorbing material, spacing, open area and length of treatment. The methods commonly used for applying acoustic materials for the reduction of sound in air passages can be classified comparatively, indicating relative attenuation as a function of frequency for each treatment. The ducts can be treated with absorption materials by these methods :

1) Lining in the duct, either rectangular or round, for its entire perimeter. This method is most effective in reducing noise at a narrow frequency range, the location of which is dependent on the treatment. Satisfactory results are usually obtained by treating the duct for a distance of at least 10 times the average of its cross sectional dimensions.

2) Splitters or parallel baffles equally spaced running in the direction of the air movement. This method is also effective in a narrow range as for duct lining.

3) Lining the far side of a right-angle bend of a duct gives the maximum attenuation occurring at middle and high frequencies.

4) Special soundstream absorbers made of curving obstructions in the duct that eliminate straight-line transmission of sound and movement of air. This method is effective over a comparatively wider range in frequency, with the highest attenuation occurring at middle and high frequencies.

5) Staggered baffles like soundstream absorbers direct the sound transmission against sound-absorbing materials at various angles in the duct. This method is equal in effectiveness with soundstream absorbers.

Absorptives materials installed in ducts should not only be highly absorbent, but also fireproof, moisture resistant, odorless, vermin proof and have a surface that will not materially increase friction losses.

Installation methods for acoustic tile.

There are a variety of methods for the installation of acoustic tile developed to cope with almost any structural condition, old or new. Strictest fire regulations can be met by the proper selection of materials and the manner of their application. They can be applied directly to an acceptable surface or suspended to form a new ceiling with ready access to the space above to accommodate pipes, conduits and ducts.

The principal methods of installation of acoustic tile and the various mechanical suspension systems are available from producers' catalogs with technical data and descriptions. The acoustic tile must be selected to suit the method of application, observing that the sound absorption varies with the method of mounting. General descriptions follow, outlining the various installation methods and systems in common use :

1. *Nailed, stapled or screwed applications.*

Perforated or slotted fiber-type acoustical tile can be applied only with nails or screws. The holes in the four corners of the tile are used to nail or screw through for concealment. The nail used is a special double-headed nail. The screw is a special type also applied with a small electric jig. Some producers make a special tile with an interlocking V tongue-and-grooved joint that permits nailing or stapling one or two tongues that are covered as the tiles are applied. This method is generally used with open coiling joists which are bridget with 1- by 4-in. nailing strips spaced 12 in. center to center for the 12- by 12-in. size tile. Generally, a felt applied over the entire ceiling area ahead of the tile will reduce the chance for infiltration which will eventually cause soiled or dust spots at the joints. Similar wood strips applied over irregular or broken plaster ceilings can provide a suitable and level surface for nailed, stapled or screwed-on tile.

Wood strips for furring should be kiln-dried soft wood, 1 by 3 in. or larger, and generally installed not to exceed 12 in. on centers. Where structural framing exceeds 24 in. on center spacing, cross framing of 2- by 3-in. or 2- by 4-in. strips at 24 in. on centers should be used to assure rigidity when the acoustic material is installed.

2. *Adhered-to-plaster application.*

The adhered method is widely used for installing acoustic tile because it is fast, clean and economical. Small spots of adhesive are placed on the backside of the tile, pressed and slipped into place against the ceiling surface. Some manufacturers use splines to insert into slits or kerfs in the edges of adhered tile to assure an even surface. By using this method fiber tile can be applied to surfaces that are complex curves by varying the thickness of pads of adhesive and by kerfing the back of the tile to permit a small curve. When building a new plaster base for acoustic tile, it is necessary to apply only the two base coats and omit the finish coat. This method meets the requirements of many building codes for noncombustible application for both fiber and mineral tiles.

New concrete or plaster backing surfaces should be tested for moisture before the installation of acoustic materials. About six months in place is generally required for drying new concrete, while it takes four or five weeks before new plaster can be considered ready.

For old concrete, gypsum board or plaster surfaces that are porous or dusty, application of a wall size is recommended. Old painted surfaces should be tested by installing only a single tile for 48 h. If the paint has not been softened by the cement upon removal of the test tile, the work can proceed safely. If the paint has softened, it should be removed before applying any acoustical material, or a mechanical fastening used. Cement alone should not be used for large units. Units exceeding 12 by 24 in. need supplementary mechanical fastenings in addition to the cement.

3. *Adhered-to-gypsum-board application.*

Fire safety is very important in connection with the suspended-type acoustic ceiling and is accomplished with noncombustible mineral tile adhered to fire resistant gypsum board as a backing. A light metal suspension system is adaptable to the fastening of the sheathing of gypsum board, usually 2- by 8-ft. panels, in the special metal splines or by annular nails into an anchored bar. The gypsum board for this purpose has an asphalt impregnated core and water-repellant paper coat to guard against moisture that might cause sagging or dimensional change. The surface of the sheathing is smooth and is a good base for the application of acoustic tile by the adhered method.

Where gypsum board, lath or sheathing are to be installed below wood joists as a surface for cementing, it is important for finished appearance that a level base be provided. Gypsum materials should not be applied directly to wood joists because they are not level and also subject to a small amount of turning. By using wood nailing strips 1 by 3 in., or larger, with the necessary shimming, a firm and level backing can be provided. Spacing of such wood strips depends upon the thickness of the gypsum material to be used and in accordance with manufacturers' recommendation. Before using a gypsum back the manufacturer of the product should be consulted to determine if it has any coating that might make it unsuitable for adhering acoustic material with cement.

4. *Suspended system with concealed fastening.*

Ceilings are generally suspended to provide space for utilities, to conceal structural systems, and to provide a lower ceiling level. Lighting fixtures and air-conditioning outlets can be readily mounted flush with the ceiling.

Suspension systems are generally of a special type to be selected from manufacturers' catalogs to suit the individual job and the type of tile to be used. They generally consist of a grid of 1 1/2-in. channels suspended 4 ft. on centers from metal strap or wire hangers. In the concealed method, a T- or Z-shaped spline fits into a kerf in the tile, and a special clip secures the spline to the supporting channel, and as each row of the tile comes into place the preceding spline and clip is concealed. The system requires no backing material and the tile is the only ceiling material.

Framing members for the suspension system should be leveled with a water level before installing the suspension members and before beginning the application of acoustic material. The suspension system should provide for its members to be locked together to prevent slippage. The design of a suspended acoustic system should be made in accordance with the recommendation of the manufacturer of the acoustic material covering the method of suspension and the thickness and type of acoustic material.

5. *Suspended system with exposed fastenings.*

The exposed fastenings in a suspended acoustic tile system has the special advantage of making the space above the ceiling accessible. Another advantage is the possibility of substituting translucent plastic panels for some of the acoustic tiles to admit light from concealed fixtures above the panels.

The standard method for most types of suspended ceilings uses a 4-ft. grid of 1 1/2-in. channels to which shaped metal members are clipped 24 in. apart. Acoustic tile, size 12 by 24 in., rests on those exposed shaped members in a manner permitting individual tiles to be lifted and set aside for ceiling space access. Replacement consists of seating the original tile in place again, giving no indication of its removal.

Variations of the systems described are made by the different manufacturers using special shaped members, clips and fastenings. Clips are made to hold tile to 3/4-, 1 1/2- and 2-in. channels and to bar joists. Splines and clips are available to hold tile

by attaching directly to wood furring strips. In some systems T runners are used as a grid instead of channels and cross T's used instead of Z splines. Special shapes are required for installing metal-pan type acoustic tile which generally employ T runners 2 ft. on center suspended by adjustable hanger clips.

Working conditions at the site.

For the best performance and appearance the installation should follow accepted techniques and under the proper conditions at the site of the work. It is recommended the job have a temperature of 70° F. with a relative humidity of 55 % maintained as nearly as possible before, during and after installation. If climatic conditions do not permit this temperature and humidity, then conditions which will prevail during occupancy should be held before, during and following the installation of the acoustic treatments.

It is best if all plastering, concrete, ceramic tile and terrazzo work be complete and dry. Doors and windows should be in place and glazed. Heating and cooling systems should be ready for operation when necessary. Roof decks of concrete and gypsum should be dry, and any spaces between decks and suspended ceilings should be vented adequately to the outside. Thermal insulation should be first used on the topside of roof decks when the temperature differences betwen interior and exterior are substantial at any season before cementing tile directly to the underside of the deck. Lighting should be observed, particularly if it strikes the areas for treatment at a sharp angle causing long shadows of slight unevenness of joints, resulting in unsatisfactory appearance of the work. Surfaces of concrete, plaster, gypsum board or furring strips to receive accoustic material should be level without irregularities. No acoustic material should be applied until backing has been examined and accepted as satisfactory. Since acoustic treatments are increasingly important in modern interiors, the selection of the right time to install these materials may mean the difference between an attractive or unattractive interior.

Conclusion.

Acoustic problems can usually be solved by the application of fundamental principles of sound control combined with engineering judgement and experience. These problems can be classified as sound conditioning in the manner air conditioning applies to control of the movement of air. Many noise problems will be avoided or eliminated by good planning and early incorporation of noise-control measures that will result in savings in time and money.

The solution of a noise problem follows certain definite steps beginning with an analysis of the levels of offending noise and the establishment of a criterion. The nature and extent of the problem must be clearly defined, and the kinds of noise sources and their number must be known as well as the relative importance and magnitudes. Acceptable noise levels must be determined for a satisfactory solution that will provide for noise quieting for an environment in which hearing is good, or to insulate noise from quieter surroundings. When the conditions of a problem are known and a criterion selected, the amount of reduction of noise should be determined. This is done by taking the differences measured in decibels between the offending noise level and the level of the accepted criterion. With this known, the noise-control measures required for solution can be determined to bring about the solution of the sound problem.

Acoustic treatment when used for noise reduction is for the purpose, as far as practical, of eliminating the disturbance created by excessive sound reflection. The effects of absorption in reducing the disturbance does not lend itself readily to a precise evaluation because disturbance and comfort are human manifestations, variations of which are not measurable directly related to changes of sound conditions that are effected in a room on the introduction of absorbing material. Also, because rooms in which absorption is used for reducing

noise vary so greatly in size, shape, amount and distribution of absorbing materials and in the kind and locations of sound sources, the theory is very complex and not always adequate for accurate prediction for the behavior of sound and the effects of absorption. Existing theory, where applicable, coupled with wide experience will make possible successful treatments for noise reduction. Treatment for comfort alone by providing absorption in excess of what can be distinguished by ear serves no useful purpose. For practical and economical reasons, only the required amounts of absorption should be used to suit the size and shape of the room and the intensity and distribution of noise source to insure satisfactory control of reflected sound. Treatment of a room is seldom strictly for purposes of noise reduction but is generally combined with good hearing.

Treatment for audition as it relates to sound control consists of the application of acoustic material having an absorption coefficient that permits reverberating sound to diminish within proper limits, and is concerned with clarity and distinctiveness of speech and music to insure natural and effortless hearing. The amount of treatment should be enough to control satisfactorily the reverberation as amounts in excess of this requirement are not only uneconomical but may create a « dead » quality to the room without benefit to the wanted sound. Generally, larger amounts of absorbing materials are used for correcting noisy conditions in a room used for working space than would be desired or required for acoustic treatment of the same room if used for hearing speech or music.

Noise isolation is a sound-control measure that early planning will take cognizance of distance and space as the best and most economical means of insulation. Where this is not possible, massive impervious barriers must be used to isolate sound within a building. Absorbing blankets, acoustical tile and thermal insulation materials have poor isolation qualities because they are usually transparent to sound, lightweight and porous. Special systems for noise isolation are also available as well as special doors and door gaskets that can help to isolate a noise within a given area.

Vibration isolation usually involves the separation or isolation of a vibrating source from some sounding material to which the source is attached. Resilient mounts of springs or resilient materials can appreciably reduce vibration. It is important to choose the right mounting, properly designed and installed, or the condition will not be reduced and may be increased. To be effective the vibration isolation must be completely isolated. Any ties, such as bolts, pipes, ducts or cable, between a vibrating source and other surfaces, such as a wall, will transmit vibrations even though precautions have been taken for mounting of the vibrating machinery. It is necessary to insert into such ties and lines some type of material providing a vibration break. This may be a canvass sleeve, loops or coils or commercial resilient sleeves and connections.

Sound attenuation in ducts used in air conditioning systems and for ventilating purposes is accomplished by recognized methods of treatment that provide for soundabsorbing materials being installed inside the ducts. The various methods are best adapted to certain frequencies, but it is possible with a combination of methods to reduce noise at any frequency.

Materials with smooth impervious surfaces, like plaster, wood, concrete and glass, are not good sound absorbers. Porous materials, such as mineral and glass wool blankets and fiber tile, retain incident sound energy and are known as good absorbers of sound. As an acoustic application they admit sound energy that is absorbed in different amounts for different materials, varying with material thickness, frequency of the incident sound, the angle of incidence of sound, and the method by which the material is mounted. If correctly used, sound- absorbing material, such as acoustic tile, can be effective in the reduction of noise, but they are not the answer to all noise problems, and may in certain instances be responsible for creating undesired conditions.

There are many acoustic products available with a wide range in effectiveness, beauty, ease of maintenance, manner of application and cost. Selection of the proper material to suit the acoustic design is important.

Just a few years ago the reverberating vocal megaphone announcements of trains competed with the noise and confusion of railway terminal concourses and waiting rooms. Today it is the public address systems that must compete with disturbing noise factors in railway terminals. While the large metropolitan stations are not always ameniable to acoustic treatment, particularly those of monumental design, the noise in many new and remodeled stations has been reduced through the use of acoustic materials. Effective use of sound conditioning can generally be made in terminals in spite of the aggravated problems, such as high peak capacities of travelers, highly reflective hard surfaces of polished marble walls and terrazzo floors, which if allowed will reverberate the numerous voices, footsteps and other sounds and noises to a point of near confusion. Sound treatment can be extremely effective in creating a quiet atmosphere practically demonstrated by results in many terminals and smaller stations.

In railway offices it is common business practice to gather a large number of workers and business machines within a single room, which may result in a noise condition that will increase fatigue and lower the efficiency of office workers. Speech can be unintelligible even at short distances, noises from distant sources in the room can seem almost as loud as that from sources near at hand, telephone conversation can be difficult because of the effect of the room noise, and because of the loss of intelligibility and noise, persons speaking will raise their voices above the normal level, in this manner increasing the general noise throughout the room. Also, the actual intensity level of the reverberant sound is greater than it would be in the same room with absorbent material.

While the principles for noise quieting in offices and other similar work areas are the same for the industrial environment, the noise levels are considerably higher, and general conditions as to the structure and character of the noises and grouping make the problem very complex. The reduction in the noise level in the shop may be less than would be expected on the reverberation theory, but workers report treated areas seemed to be less noisy. The explanation, perhaps, is that while noise originating near the work was not reduced, the effect of acoustical treatment on reverberation and noise from distant sources was to improve the shop conditions. Industrial management is recognizing that acoustical treatment is an important consideration for employees' welfare and for industrial economy.

A survey taken among the members of this subcommittee representing 21 railroads in the United States and one in Canada indicates that no action has been taken among these railroads in the direction of noise quieting in shop facilities. The information reported in connection with the industrial environment is the experience in industry apart from the railroads. Railway shops and facilities differ vastly from most industrial plants and factories and the assembly line production methods of manufacture. Most shop buildings for railroads are of necessity large in area and high, enclosing considerable space which in itself is the best means of noise quieting.

The need for sound control occurs when people gather indoors, varying in accordance with requirements for quiet, audition and noise insulation. These requirements are common to many railroad facilities and in relation to their need advance the recommendation for sound control in railway buildings.

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[656 .2 (4 + 73)]

The railways of Western Europe and America and their economic development,

by Dr. Robert KALT.

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I. The general picture.

The most important railways of Western Europe now operate some 199 540 km of lines (Switzerland, Western Germany, France, Italy, Spain, Portugal, Great Britain, Belgium, Holland, Denmark, Norway, Sweden, Finland, Jugoslavia, Greece and Turkey). The average density of the system — which varies between 10 km (Turkey) and 161.2 km (Belgium) — is 45.2 km of lines per thousand square kilometre. 14.2 % of the Western European systems are electrified (in 1938 : 9 %) and 33.3 % are double or multiple track. The total number of railway employees which has increased by 4.9 % since the last prewar year, is 2 297 000, i.e. 11.5 per kilometre of line; whilst the number of gross tonnes-kilometres transported has increased from 333 000 to 370 000 per employee, i.e. an increase of 11 %.

The *United States* with a railway system of 344 507 km has a density of 44 km per 1 000 km^2, i.e. approximately the same figure. On the other hand, in the United States (Diesel)-electric traction amounts to 74 % (calculated from the stock of locomotives), whereas before the war 89 % of all the locomotives were steam. On the other hand, multiple track lines only amount to 13.7 % of the whole. Owing to the immense size of the country, and the long transport distances, which are two to three times as great as in Europe, there are only 3.5 employees per kilometre of line, though the total number it is true is 29 % greater than in 1938. The output in TKBR per employee, six times greater than in Europe, has increased from 1.5 to 2.4 million, i.e. an increase of 60 %.

Table I below gives an idea of the *volume of traffic* and the *traffic position.*

In 1954, the railways of Western Europe carried a total of 4.75 thousand million passengers, i.e. 27 % more than the average for the years 1937 and 1938. The average journey per passenger also increased by 3.9 km giving the astronomical figure of 176 thousand million passenger-kilometres (1 181 times the distance from the earth to the sun) or 42 % more than in the last two years before the war. Owing to the speeded up turn round of the stock, each seat occupied travelled 22 900 km i.e. 66 % more than before the war. The increased user is also shown by the fact that in 1954 each seat available was occupied 1.7 times per day, compared with 1.1 times in 1937-1938. The development of a *taste for travelling,* which lies at the bottom of the increased traffic, is reflected in the figures relating per passenger. In 1954, for example, every inhabitant of Western Europe used the railway 14.7 times (in 1937-1938, 12.7 times) and travelled a total distance of 543 km (422 km in 1937-1938). In general, all the traffic figures for 1953 and 1954 show an increase, this latter year continuing the steady tendency to develop.

Although the train mileages have increased less in the case of the passenger traffic than in the case of freight traffic, the amount of *goods carried* has not been able to show any increase over prewar

TABLE 1.

a) **All the railways of Western Europe.**

	1937/38		1953		1954	
Train mileage (million km)	2 256	100	2 361	105	2 430	108
Passenger trains (million km)	1 500	100	1 505	100	1 566	104
Freight trains (million km)	756	100	856	113	864	114
Passengers carried (millions)	3 732	100	4 622	124	4 749	127
Tons carried (millions)	1 061	100	1 024	97	1 048	99
Passenger-km (thousand million)	124	100	172	139	176	142
Ton-km (thousand million)	136	100	185	136	189	139
Distance travelled per passenger (km)	33.2	100	37.2	112	37.1	112
Distance travelled per ton (km)	128.1	100	180.7	141	180.3	141
Passenger-km per seat (thousands)	13.8	100	22.4	162	22.9	166
Ton-km per ton-capacity (thousands)	3.4	100	4.7	138	4.8	141
Passenger-km per inhabitant	422	100	531	126	543	129
Number of journeys per inhabitant	12.7	100	14.3	113	14.7	116

levels. However the transport distances have increased by 52.2 km, i.e. 41 % which took the number of tonnes-kilometres to 189 thousand million, an increase of 39 %. The user of the load capacity was increased from 3 400 to 4 800 km per ton of useful load, in other words an increase of 41 %. *Safety of the traffic* on the railways is remarkably good; in fact the annual average (1952-1953) for accidents only amounted to 8.4 persons per 100 km of line in Europe and 6.9 in the United States.

A *comparison* of European railway traffic with that of the United States brings out the essential differences.

TABLE 2.

b) **Railways of the United States.**

	1937/38		1953		1954	
Passengers carried (millions)	475	100	486	102	449	95
Tons carried (millions)	1 462	100	2 671	183	2 416	165
Passenger-km (thousand million)	37.5	100	51.0	136	47.1	126
Tons-km (thousand million)	475	100	975	205	882	186
Passenger-km per inhabitant	288	100	321	111	295	102
Number of journeys per inhabitant	3.6	100	3.0	83	2.8	78

North American railway traffic is characterised by the considerable predominance of freight traffic (19 times greater than the passenger traffic, whereas they are about equal in Europe), the long transport distances which are about triple in the case of the passenger services and double in the case of freight, as well as the great amount of passenger traffic lost to road and air services. In addition, the fall in the volume of transport between 1953 and 1954 shows that the American railways are more sensitive to economic fluctuations.

As public traffic, and in particular railway traffic, can be measured exactly, it has an important *representative function:* the traffic is the thermometer of economic activity. Whereas the world population has increased by 21 % compared with pre-war years, in Western Europe by 10 ½ % and in the United States by 23 %, estimated world production (without the Soviet Republic and China) of all the important primary foodstuffs has only increased by 11 %, that of raw materials and industrial accessories by 48 %. At the same time, the industrial production of certain European countries has increased by 47 %, and that of the United States by 136 % (figures taken from the O. N. U. Annual for 1954). It is interesting to note, as we have just done, that the railway traffic in Western Europe has grown by 42 % in the case of passengers (United States 1953-1954, + 31 %) and in the case of freight, by 39 % (United States, + 95 %). The parallelism of the evolution is most striking.

A comparison between the railways and *other transport undertakings* is given in Table 3.

Whereas the European maritime freight traffic, which has increased by 7 %, only represents a bare quarter of the traffic carried by rail, *motorisation* of road traffic has made appreciable progress, particularly in the case of traffic carried by lorry. But the number of motor vehicles in Europe, the only available figure for comparison, has also exceeded by 8 % the increase in railway traffic, whilst the figure for lorries exceeds that of the railway by 96 %. The relative delay in the development of American road freight traffic is explained quite naturally by the higher degree of saturation in motor vehicles : in fact the vehicle density is 11 times greater in the U. S. A than in Europe, in the case of passengers, and 4 times greater in the case of freight.

TABLE 3.

	Western Europe	Index (1937 = 100)	United States	Index (1937 = 100)
Freight traffic from 21 European ports (1951/52), millions of t.	244	107		
Motor vehicles (1953, in thousands .	8 357	150	46 290	182
Lorries (1953), in thousands	4 442	267	9 304	216
Air traffic : passenger-km (1953), millions	6 245 (1)	2 559	29 203	3 637
Air traffic : ton-km (1953), millions	219 (1)	1 210	683	4 910

(1) Switzerland, Belgium, France, Great Britain and Sweden.

Air traffic has developed to a striking degree. In Europe, passenger air journeys multiplied by more than 25 (= 3.6 % of the railway traffic) and in the United States by 36 (= 62 % of the railway traffic). In the case of air freight traffic, the increase was twelve times in Europe (= 1.2 ‰ of the railway) and 49 times in the United States (= 0.8 ‰ of the railway.

II. Study by country.

In the *different countries* of Western Europe, railway traffic developed as follows, according to Table 4 (year 1954 compared with 1937-1938).

From the mass of resulting indications, we will retain a few essential facts. The *mileage* of the trains, two thirds of which relate to passenger trains, generally increased, except in France, Great Britain and Belgium. The increase is particularly striking in the case of Norway, Sweden and Turkey. The total increase represents 4 % in the case of passenger trains and 14 % in the case of freight trains. *Passenger traffic* declined in France and Great Britain, whilst it was more than doubled in Austria, Italy, Spain, Portugal, Holland, Denmark, Sweden, Jugoslavia and Turkey. *Freight traffic* declined in Western Germany (calculated per kilometre of line of the present Bundesbahn and the former Reichsbahn), in France, Italy, Great Britain, Belgium and Greece; an increase of more than 50 % occurred in Austria, Sweden, Jugoslavia, and more particularly in Turkey. The *distance travelled per passenger* (total + 12 %) and above all per ton of freight (total + 41 %) show the increase in *long distance traffic,* which may make up by the

TABLE 4.

Country	Train mileage		Transport				Transport distance in km per			
			Passengers		Tonnes		passenger		ton	
	Tr.-km (millions)	Index 37/38 = 100	Millions	Index 37/38 = 100	Millions	Index 37/38 = 100	1954	37/38	1954	37/38
Switzerland	68.1	148	205	182	20.6	141	29.8	25.3	128.6	117.6
Western Germany	537.0	122(1)	1 453	152	231.0	97	24.6	27.4	188.3	159.3
Austria	63.9	122(1)	135	241	41.8	168	38.5	41.1	146.2	139.3
France	351.0	80	500	84	169.0	95	52.6	44.0	244.4	177.5
Italy	209.3	121	390	250	45.4	92	55.1	70.9	282.0	231.0
Spain	93.1	123(2)	114	228	26.9	117	69.3	60.0	263.9	161.6
Portugal	18.6	145	52	211	3.7	103	27.5	30.3	183.8	152.5
Great Britain	609.0	92	1 020	80	288.0	82	34.0	26.2	125.7	74.6
Belgium	72.7	82	227	106	62.5	71	33.5	29.4	92.2	70.2
Netherlands	68.9	129	171	214	25.0	125	40.9	38.2	136.0	150.0
Denmark	37.8	131	110	217	6.0	138	27.3	29.7	188.5	126.5
Norway	31.1	164	41	193	13.5	114	38.2	31.9	96.3	65.5
Sweden	125.8	232	111	243	37.4	174	52.2	49.3	229.9	170.0
Finland	37.7	122	35	159	17.9	121	57.0	52.3	229.0	165.5
Jugoslavia	69.0	125	147	271	38.9	254	44.2	52.7	224.7	212.4
Greece	7.1	148	6	120	1.5	97	90.9	72.7	184.9	129.2
Turkey	29.5	218	62	350	10.8	338	62.9	51.3	351.8	297.1

(1) year(s) of comparison 1936/1937 (2) year(s) of comparison 1934/1935

TABLE 5.

Country	Density of system, km of line per 1 000 km² (1954)	Transport distance in km per inhabitant 1954	Transport distance in km per inhabitant 37/38	Passenger km per seat (thousands) 1954	Passenger km per seat (thousands) 37/38	T.-km per t. capacity (thousands) 1954	T.-km per t. capacity (thousands) 37/38	Freight traffic receipts (Passenger traffic = 100) 1954	Freight traffic receipts (Passenger traffic = 100) 37/38	Operating coefficient 53/54 %	Operating coefficient 37/38 %	Number of employees per 100 000 trains-km 1954	Number of employees per 100 000 trains-km 37/38
Switzerland . . .	70.5	1 249	678	26.2	12.9	7.7	6.6	126	119	71.0	71.0	54.7	60.0
Western Germany .	124.4	728	683	26.0	12.9	7.6	6.3	223	231	107.8	92.7	87.6	89.5
Austria	71.4	743	343	25.7	7.6	9.2	5.6	360	232	126.1	99.0	112.2	108.6
France	74.8	614	635	19.9	13.9	5.0	3.3	199	248	107.2	114.0	108.3	118.1
Italy	55.0	457	260	34.7	21.5	5.2	4.4	90	163	124.7	83.0	73.2	79.6
Spain	26.0	277	119	34.3	10.6	5.9	3.8	230	314	113.2	60.8	147.4	123.8
Portugal	38.7	166	100	23.0	14.7	4.5	5.0	131	142	113.2	93.9	141.9	159.4
Great Britain . .	126.4	667	703	13.6	13.3	2.4	1.7	235	117	94.0	83.6	96.8	87.8
Belgium	161.2	873	750	21.2	13.6	3.5	3.2	192	199	100.1	106.8	103.9	85.3
Netherlands . . .	98.4	667	351	71.4	19.2	6.6	6.3	73	74	97.4	88.8	47.4	56.9
Denmark	60.6	682	395	26.8	14.1	4.6	3.2	78	65	114.0	100.4	77.3	71.3
Norway	13.5	470	241	23.1	12.3	6.6	5.4	134	124	123.5	111.0	89.4	90.5
Sweden	34.3	806	357	24.0	21.8	8.3	8.2	191	170	99.8	81.8	54.2	54.6
Finland	14.4	463	319	29.0	21.3	9.3	6.6	374	252	98.0	82.0	95.8	94.2
Jugoslavia	45.2	382	185	34.0	16.9	8.4	4.2	409	255	88.5	100.0	161.7	146.4
Greece	11.3	76	56	67.0	23.5	3.2	2.4	106	129	127.1	92.4	118.6	141.7
Turkey	10.0	173	53	56.5	16.7	10.6	4.1	258	242	67.3	67.2	105.6	163.4

increase in the mileage for the partial decline, especially in the case of freight traffic, of the goods transported under the effects of motor competition (for local traffic) on the one hand and on the other the integration to meet world economic conditions. Owing to changes in the traffic, passenger mileage was slightly reduced in Western Germany, Austria, Italy, Portugal, Denmark and Jugoslavia; a reduction in the distances over which freight was carried was only noted in Holland.

The total transport distance (total passenger-kilometres) per inhabitant shows, except in France and Great Britain, very differing *railway journey lengths* from one country to another (Table 5). Today Switzerland heads the list, with 1 249 km [1] whereas the Greeks only travel 76 km. The highest percentage of increase is in Turkey (more than tripled); the Austrians, Spaniards, Swedes and Jugoslaves all doubled their mileage; in certain countries an increase in foreign tourist traffic has also to be taken into account.

The *number of seats available* which has fallen off on the whole, from 9 million to 7.7 million, but of improved quality, were on the whole better used by passengers, as the increase in the number of passenger-kilometres shows, except in Great Britain, where it remained stationary. In the same way, the traffic per ton of *loading capacity* increased, the latter remaining unchanged at 39 million tons. The only decline was in Portugal. The number of employees per hundred thousand train-kilometres is a clue to the *productivity of transport work.* Today Holland heads the list, followed very closely by Sweden and Switzerland. At the other

(1) The long distances travelled per inhabitant in Switzerland is obviously due in part to transit traffic, international tourist traffic and the journeys made by foreign travellers.

end of the scale there is Jugoslavia, Spain and Portugal. Except in Austria, Spain, Great Britain, Belgium, Denmark, Finland and Jugoslavia, productivity increased, as the relative decrease in the number of employees shows.

Except in Italy, Holland and Denmark, *receipts from freight traffic predominate,* and in Western Germany, Austria, Spain, Great Britain, Finland, Jugoslavia and Turkey these represent more than double the receipts from passenger traffic. In Italy, the position has been reversed since 1937-1938. According to the *operating coefficients,* seven railway administrations alone (Switzerland, Great Britain, Holland, Sweden, Finland, Jugoslavia and Turkey) have succeeded in the average for the years 1953 and 1954 in covering their operating costs by their receipts. The ten others show an operating deficiency. Before the war, only four had a deficit. The increase in the number of undertakings showing a deficit is due in general to the considerable increase in operating costs to which the tariffs have only been adjusted tardily or insufficiently, and above all to the loss of traffic carried at high rates to other transport undertakings. However, in spite of these difficulties, the *Swiss Federal Railways* show the most favourable operating coefficient (after Turkey) of all the railways, including those of the United States, Canada and Japan.

The Swiss Federal Railways obtained the highest passenger receipts on the Continent, and come third (after the Saar and Luxemburg) in the case of freight receipts per kilometre operated. With a figure per head of 10 400 Swiss francs (1954), they also have the highest labour costs in Western Europe. Thanks to electrification, the traction current used by the C. F. F. (42.5 Swiss centimes per locomotive-kilometre) costs the least, whereas the Finnish Railways, using steam traction, have to spend more than four times as much under this heading. On the other hand, it must not be forgotten that the *output in useful kilometres of the organisation of the trains* would appear capable of *improvement.* For example, if we compare the train mileage and traffic for 1954, it is seen that the C. F. F. as regards the number of passenger-kilometres per train-kilometre, which is 120.8, only comes tenth in Western Europe, after Turkey, Jugoslavia, Spain, the Saar, Belgium, France, Italy, Holland and Austria, though exceeding the general average for the Continent by 7.7 %. Against this, in the case of freight traffic, the figure of 152.3 t-km per train-kilometre is below the European average of 30.4 %, and due in part to the small loads carried in the freight wagons, and only exceeds those of Denmark, Spain and Portugal. There is undoubtedly great scope for rationalisation here, and this is indeed the subject of an investigation now being carried out which will be based on data concerning the structure of the traffic.

As far as the *financial results* are concerned, it is only possible to make relative international comparisons, and we will merely compare the railway traffic receipts with the *national income* (Table 6). This significant criterion shows that for all the countries of Western Europe there is a decrease as far as the railway is concerned of 12 % in passenger traffic and 9 % in freight traffic; in the United States the decline was respectively 55 % and 31 %. There was only an increase in the percentage compared with the national income in the case of passenger traffic in France, Portugal, Norway and Sweden, and in the case of freight traffic, in Great Britain, Norway, Sweden, Finland and Turkey. Denmark remained stationary. The *total loss in receipts* due to insufficient adaptation of the tariffs, modifications in the traffic structure and the loss of lucrative traffic in Western Europe can be estimated as 813 million Swiss francs (1953) in the case of passenger traffic, and 1 263 million in the case of freight traffic; in the United States, the loss of receipts amounts to

TABLE 6.

Country	Passenger traffic receipts (as a % of the national income)			Freight traffic receipts (as a % of the national income)		
	1953 %	Index (38 = 100)	Decline/increase millions of Swiss francs	1953 %	Index (38 = 100)	Decline/increase millions of Swiss francs
Switzerland	1.46	96	— 12.2	1.72	90	— 35.8
Western Germany (1).	1.26	80	— 273.4	3.09	80	— 668.8
Austria (1)	1.20	62	— 48.3	3.62	78	— 84.5
France	1.24	109	+ 143.2	2.62	91	— 303.8
Italy	0.99	92	— 50.2	0.96	53	— 244.8
Spain	0.57	52	— 78.7	1.32	75	— 95.3
Portugal	0.66	102	+ 0.9	0.75	80	— 10.4
Great Britain	0.78	70	— 426.9	1.79	107	+ 228.3
Belgium	1.16	87	— 39.5	2.28	84	— 95.7
Netherlands	1.07	96	— 9.7	0.78	93	— 12.3
Denmark	0.89	100	—	0.63	100	—
Norway	0.86	118	+ 10.6	1.19	128	+ 34.7
Sweden	1.04	135	+ 114.8	1.97	148	+ 297.6
Finland	0.72	73	— 22.1	2.58	101	+ 3.0
Jugoslavia	0.52	39	— 109.8	2.31	68	— 256.0
Turkey	0.50	86	— 11.8	1.55	108	+ 20.9
Western Europe	0.99	88	— 813.1	2.06	91	— 1 262.9
United States	0.27	45	— 2 038.0	2.93	69	— 12 208.0

(1) Year of comparison 1937

2 and 12 thousand million Swiss francs respectively. These figures are moreover *minima*.

To conclude, we also give a comparative table showing the *development of railway and road motor traffic* in certain countries (Table 7).

The development of railway passenger traffic exceeded that of the road in Spain, Holland, Denmark and Norway; motor traffic is higher in Switzerland, Western Germany, France, Italy, Great Britain, Belgium and Sweden. There is not much difference in Austria, France, and Holland, which leads one to think that the two methods of transport, encouraged by the general taste for travel, are mutually dependent from the point of view of this tendency at least. It is rather different in the case of freight traffic. With the exception of Spain and Sweden, the lorry has developed more considerably than railway transport : more than twice as much in Western Germany, Italy and Belgium. The two figures are about the same in Denmark. In *Switzerland*, the development of the road has exceeded that of the railway, compared with pre-war figures, by 37 % in the case of passenger traffic and 52 % in the case of freight traffic.

III. Résumé.

Although the railways have lost their old position of a monopoly, the development of railway traffic has, in general, in no way come to a standstill, much less suffered a decline. On the contrary, there is a great deal of life in them, as is shown

TABLE 7.

Country	Railway traffic 1953/1954				Number of motor vehicles (1953)			
	Pas.-km (thousand million)	Index 37/38 = 100	T.-km (thousand million)	Index 37/38 = 100	Motor vehicles 1 000	Index 37 = 100	Lorries 1 000	Index 37 = 100
Switzerland	6.1	214	2.55	150	211	293	48	228
Western Germany	34.6	133	42.8	114	1 129	160	919	380
Austria	5.1	222	6.0	171	75	234	52	325
France	26.1	100	40.8	135	2 020	120	1 254	202
Italy	22.0	198	12.7	111	613	226	305	372
Spain	8.0	267	7.5	203	106	—	95	186
Great Britain	33.6	101	36.7	140	2 798	153	1 070	203
Belgium	7.6	121	5.8	94	368	256	162	208
Netherlands	6.8	223	3.35	112	188	207	97	190
Denmark	3.0	200	1.1	200	158	156	85	207
Norway	1.55	221	1.35	169	91	194	82	256
Sweden	5.9	262	8.5	233	431	322	111	191

by the increase in the figures for the traffic, the train mileage and the traffic, as well as the better user of the available capacity. Railway traffic, which can form the subject of accurate statistics, is thus representative of the general economic development. In the increased economic development of the last few years, pushed on by the competition of other methods of transport and stimulating these in its turn, the railways have maintained their position brilliantly. Although railway traffic perspectives may not appear as promising as in the past, it can be stated that the railways are able to face the future with confidence. However the author thinks that today they are being called upon to make excessive tariff sacrifices, though these it is true are profitable for the national economy.

[**621** .131 (54)]

Weighbars for measuring flange forces.

(Extracted from the Annual Report 1955-1956 of the Railway Testing and Research Centre, Ministry of Railways, India.)

4.1.1. During the year, the following features of the weighbar construction were improved :

(i) Elimination of errors in calibration due to temperature effects;

(ii) Use of special magnetic material and high sensitivity galvanometers to improve the overall sensitivity of the weighbars.

The weighbar was developed by the Research Organization of the Indian Railways in the year 1937 for measuring flange forces from locomotive wheels. As originally built it had duralumin detector assemblies housed in steel shells. When fitted on a locomotive for measuring flange forces, those on the trailing coupled axle, were getting heated up to about 55° C, due to the proximity of the firebox. This increased temperature of the weighbar at the time of the actual recording greatly differed from the usual ambient temperature of 25° C at which the weighbars were calibrated. As the internal plugs of the weighbars were of duralumin, which has a coefficient of expansion of 0.000022 per ° C as compared to the steel of the outer shells which has a coefficient of expansion of about 0.000012 per ° C, the relative position of the magnetic cores and consequently secondary voltage from the weighbars varied with changes in temperature. Voltage variation observed at different temperatures are shown in the table.

TABLE 4.1.

Voltage variation with temperature in case of duralumin detector assembly.

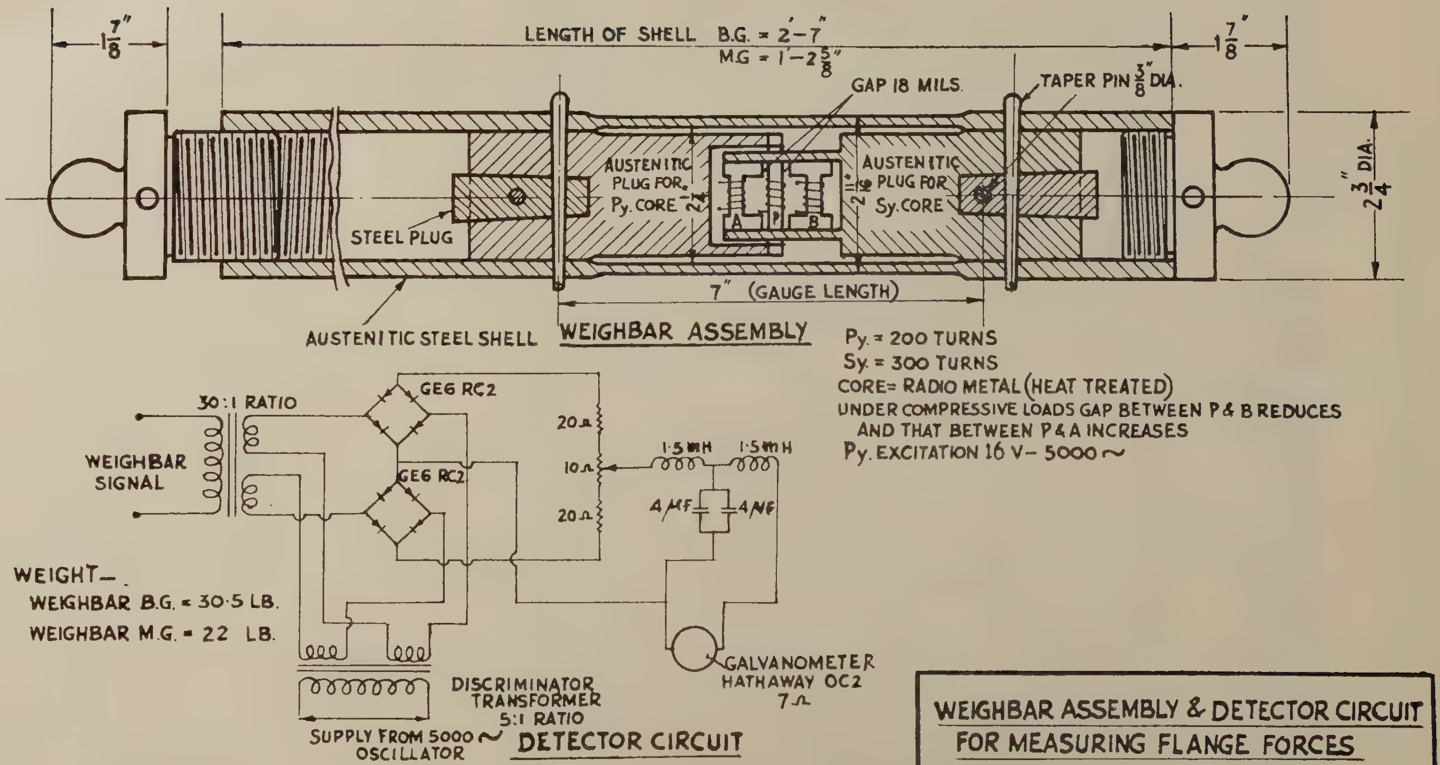
(i) Primary excitation 32 V; 5 000 c.p.s.

(ii) No. of turns : Primary — 150; Secondary — 175 and 125.

Temperature °C	Secondary voltage in volts at		Change in secondary voltage for a load of 10 tons
	No load	10 tons	
15	8.5	3.8	4.7
25	6.9	2.3	4.6
35	5.3	0.7	4.6
45	3.6	— 0.85	4.45
50	2.1	— 2.2	4.3

Percentage error at 50 °C with respect to the calibration done at 25 °C $\dfrac{4.6 - 4.3}{4.6} \times 100 = 6.5\ \%$.

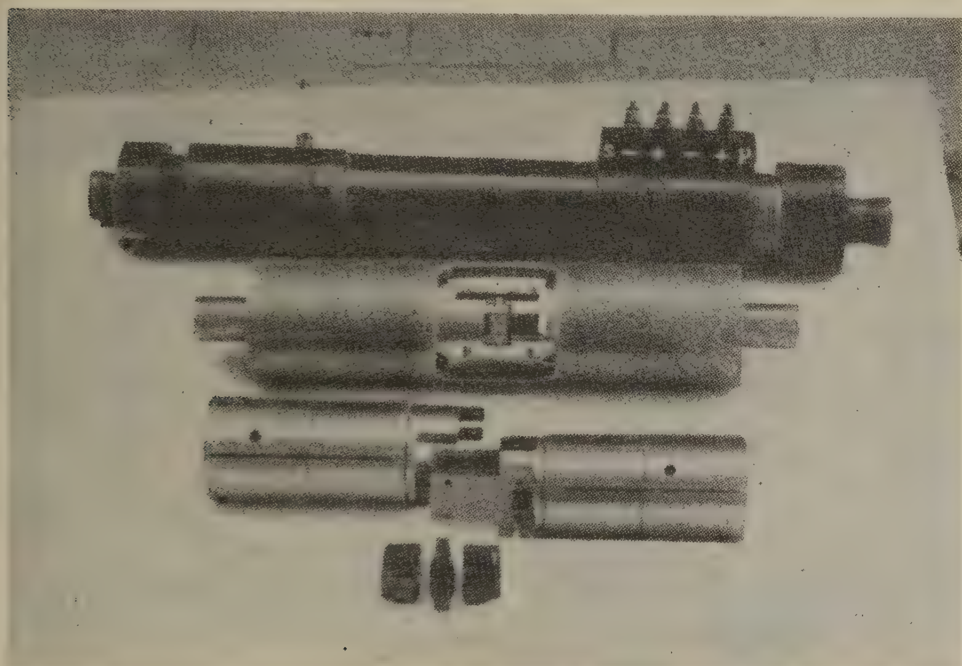
Fig. 4.1.



WEIGHBAR ASSEMBLY & DETECTOR CIRCUIT FOR MEASURING FLANGE FORCES

The design of the weighbar was such that application of the compressive loads due to the flange forces would reduce the air gap between B & P and increase it between A & P (fig. 4.1). Reference to performance characteristics of weighbars (fig. 4.2) shows that the induced voltage of the secondary windings which are connected in subtractive polarity would tend to reduce with load, as well as with increase in temperature. The combined effect of both temperature and compressive load results in shifting the relative position of the primary windings with respect to two outer secondaries beyond the working range. It could be seen from the graph in figure 4.2 that compressive loads beyond the working range reverse the polarity of the voltage of the secondary of the weighbar. This reversal had the effect of nullifying the signal from the weighbars. To overcome this defect, the weighbars fitted on trailing coupled axles were cooled externally so that the secondary voltage from a pair of weighbars was maintained well above 6 V.

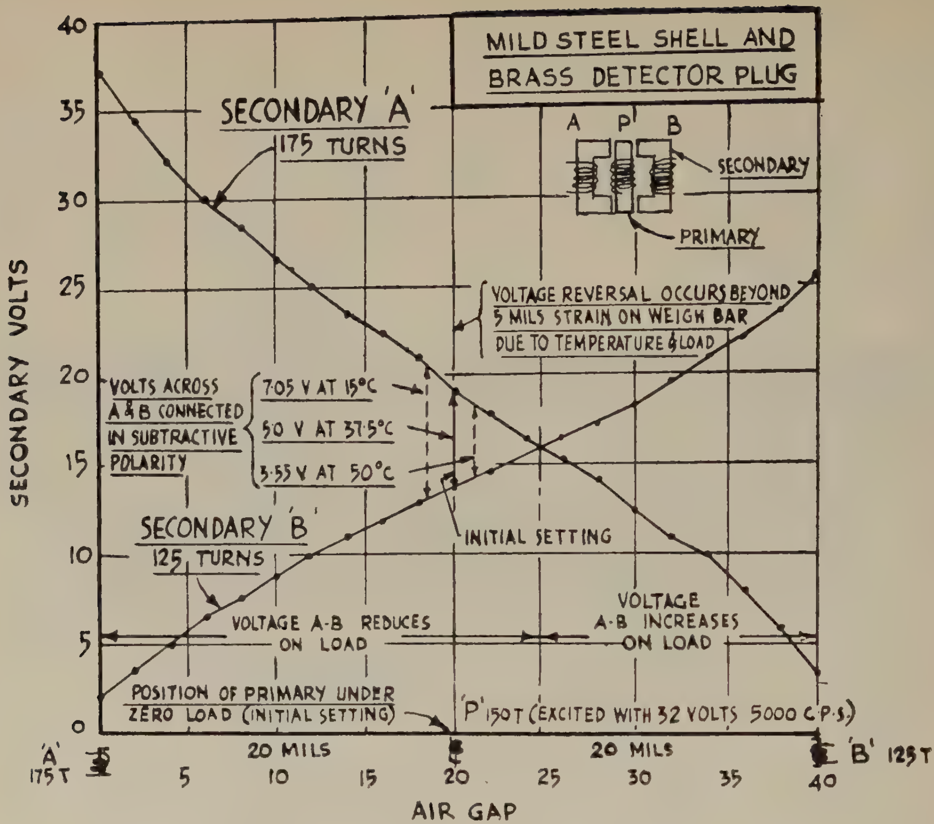
In subsequent designs, to reduce errors due to temperature variation, brass detector plugs which had a coefficient of expansion of 0.000018 per °C were used instead of duralumin. The table 4.2 hereafter gives the calibration figures obtained with the brass detector housings.

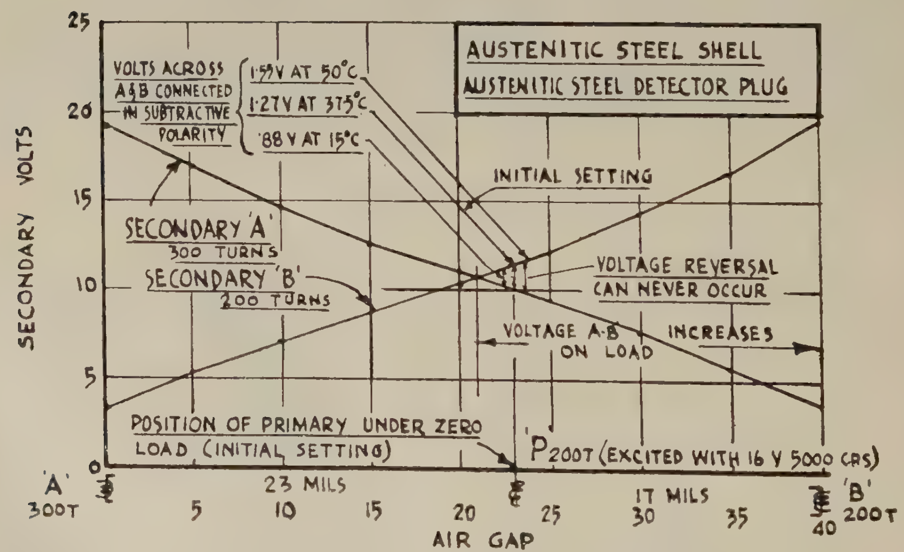


Weighbar showing the detectors and the electro-magnetic pick-up for measuring flange forces exerted by locomotives.

Reduction of no-load voltage from the secondaries with increase in temperature necessitated frequent balancing of the bridge circuits and error was still as much as 2.7 %. In order to eliminate all these defects, it was considered that weighbar shell and detector plugs should be

Fig. 4.2.





NOTE :- PRIMARY 'P' MOVES AWAY FROM 'A' AND TOWARDS 'B' FOR COMPRESSIVE LOADS ON WEIGH BAR

AIR-GAP Vs SECONDARY VOLTS
FOR WEIGH BAR TELEMETER

TABLE 4.2.

Voltage variation with temperature in the case of brass detector assembly.

(1) Primary excitation 32 V; 5 000 c.p.s.

(2) Number of turns : Primary — 150; Secondary 175 and 125.

Temperature °C	Secondary voltage in volts at		Change in voltage for a load of 10 tons
	No load	10 tons	
15	7.05	2.51	4.54
25	6.15	1.65	4.5
35	5.14	0.7	4.44
45	4.5	0.1	4.4
50	3.88	— 0.50	4.38

Percentage error at 50 °C with respect to the calibration at 25 °C $\frac{4.5 - 4.38}{4.5} \times 100 = 2.7\ \%$.

manufactured from the same material. A non-magnetic material possessing the mechanical properties similar to steel was required.

High tensile austenitic alloy steel with the following properties was imported and the shell and detector assemblies were built from it.

(i) Composition of steel used :
- Carbon 0.12 %;
- Silicon 0.6 %;
- Manganese 0.8 %;
- Chromium 18 %;
- Nickel 8.5 %;
- Titanium 0.6 %;

(ii) Permeability 1.010 to 1.014;

(iii) Brinell hardness 150 to 160;

(iv) Ultimate tensile strength 36 t.s.i.

The calibration of the weighbars manufactured out of austenitic steel is given in the table 4.3 for different temperatures.

Use of austenitic steel has reduced error in calibration due to temperature effect from 6.5 % to 1.7 %. To eliminate the reversal of the secondary voltage, the initial setting of the primary core with respect to the secondaries was adjusted such that there was an increase of voltage on application of the compressive loads.

A series of laboratory experiments were conducted to improve the overall sensitivity of the weighbar and its associated equipment by :

(i) Increase of the secondary turns;

(ii) Reduction in the air gaps A-P & B-P;

(iii) Use of high permeability magnetic material;

(iv) Manufacture of detector housing from non-magnetic material;

(v) Use of high sentivity galvanometers with high natural frequencies.

With regard to increase of turns, the maximum turns that could be accommodated in the space available was 200 on the primary and 300 on each of the secondaries. The primary turns were increased from 150 to 200 to reduce the load on the oscillator. As originally designed, the

TABLE 4.3.

Voltage variation with temperature in the case of austenitic steel detector assembly.

(1) Primary excitation 16 V; 5 000 c.p.s.
(2) Number of turns : Primary — 200; Secondary — 300 and 300.

Temperature °C	Secondary voltage in volts at		Change in voltage for a load of 10 tons
	No load	10 tons	
15	0.88	3.23	2.35
25	1.06	3.42	2.36
35	1.24	3.62	2.38
45	1.39	3.79	2.40
50	1.55	3.95	2.40

Percentage error at 50 °C with respect to the calibration at 25 °C $\dfrac{2.40 - 2.36}{2.36} \times 100 = 1.7\ \%$.

TABLE 4.4.

Variation in primary current and secondary voltage with different materials for the transformer core and detector assemblies.

Type of transformer stampings	Material for detector assembly	Change in secondary volts for a 5 mil change between primary and secondary cores	Maximum primary current at 16 V 5 000 c.p.s.
(1) Rho-metal (non-heat-treated)	Austenitic Steel	2.3 V	78 mA
(2) Do	Brass	2.4 V	82 mA
(3) Rho-metal (heat-treated)	Austenitic Steel	3.2 V	38 mA
(4) Do	Brass	3.7 V	42 mA
(5) Radio metal (non-heat-treated)	Austenitic Steel	2.1 V	77 mA
(6) Do	Brass	2.2 V	82 mA
(7) Radio metal (heat-treated)	Austenitic	3.2 V	36 mA
(8) Do	Brass	3.8 V	40.5 mA

primary was taking 128 mA at 32 V and 71.3 mA at 16 V. With the increase in the number of turns and reduced air gap, the current drawn dropped to 36 mA at 16 V excitation.

In regard to the reduction of the air gap, all that could be done was to reduce it from 20 mils to 18 mils.

Table 4.4, given above, shows the changes in secondary voltage for various materials for the transformer and the detector assembly. With brass in the detector elements, a higher sensitivity could be obtained but the use of brass had to be abandoned due to the high degree of error on account of temperature variation. Radio metal (heat treated) for the transformer stamping and austenitic steel for the detector assemblies are now being used.

The galvanometers that were used originally had an undamped natural frequency of 200 cycles with a deflectional sensitivity of 20 mm/mA/m. High sensitivity galvanometers which have an undamped natural frequency of 750 c.p.s. and a deflection sensitivity of 125 mm/mA/m have been obtained. In view of the increased sensitivity of the galvanometers no amplifiers are used in the present design and the weighbar signal is fed directly into the galvanometer after being rectified by copper-oxide rectifiers.

A comparative statement showing the alterations made in the design of the new weighbar is as follows :

	Old weighbar	New weighbar
(1) Material used for :		
(*a*) Shell	Mild Steel	Austenitic Steel
(*b*) Detector housing	Duralumin and later brass	Austenitic Steel
(*c*) Telemeter cores	Rho-metal (heat-treated)	Radio metal (heat-treated)
(2) No. of turns. Primary	150	200
Do. Secondary	175 125	300 300
(3) Excitation Primary	32 V, 5 000 c.p.s.	16 V, 5 000 c.p.s.
(4) Primary current	128 mA	36 mA
(5) No load setting of secondary voltage	5.0 V (volts reducing with compressive load)	1.2 V (volts increasing with compressive load)
(6) Change in volts per 10 ton load	4.5 V	2.4 V
(7) Overall deflection of galvanometer with zero attenuation	2.5 cm	4 cm
(8) Ancillary equipment reqd. for measuring flange forces	(1) 15 W oscillator amplifier (2) Detector and amplifier circuits using Duo diode-triode valves (3) Filter circuit (4) H. T. & L. T. Batteries	(1) 8 W oscillator amplifier (2) Copper oxide rectifiers only (3) Filter circuit (4) H. T. & L. T. Batteries

[625 .232 (42)]

British Railways prototype coaches.

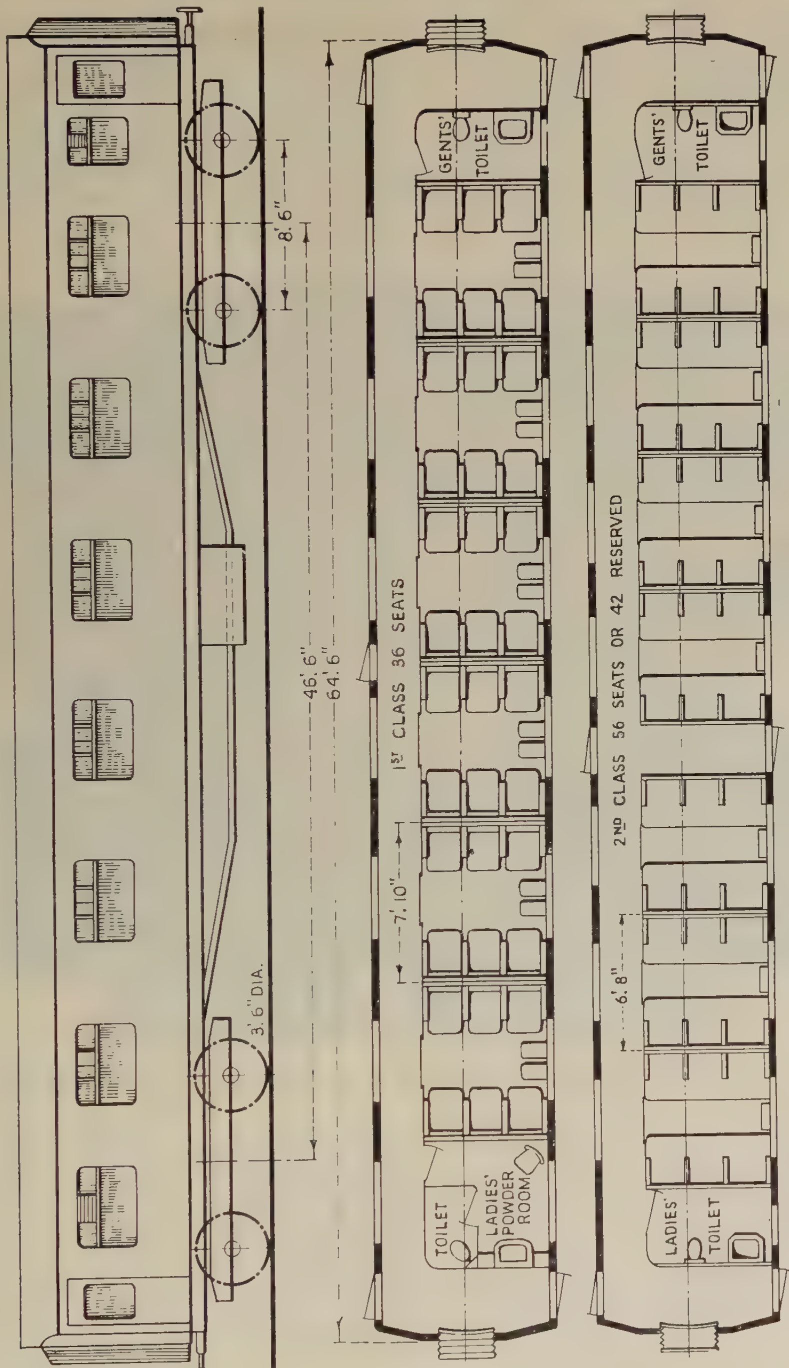
Manufacturers given the opportunity to use individual designs.

(*The Railway Gazette*, February 8, 1957.)

British Railways first class prototype coach built by the Metropolitan-Cammell Carriage & Wagon Co. Ltd.

During the period of seven years ending in December, 1962, British Railways expect to put into service under the modernisation plan about 20 000 coaching vehicles of all kinds. These will replace about 25 000 existing vehicles, including the whole of the remaining 14 000 wooden-bodied coaches. The 20 000 new vehicles will include about 7 700 main-line coaches fitted with end-gangways, and suitable for haulage by steam, Diesel, or electric locomotives.

In evolving this big fleet of new main line coaches, British Railways in collaboration with manufacturers are seeking to obtain public reaction to such developments as improved heat- and sound-insulation; revolving and reclining seats; heating in corridors; roomier compartments; and a wide range of new designs of luggage racks, lighting fixtures and other equipment. With the object of trying out these various features, the British Transport Commision authorised a programme of 14 prototype main-line passenger coaches, eight to be built by contractors and six in British Railways workshops; the stock will go into service during 1957.



Elevation of first class coach, and plan of first and second class coach, showing the respective layouts.

Interior design.

In the interior design and decor of these prototype vehicles, the contractors have been given a free hand to use their own ideas, or to utilise the services of independent design consultants, within the physical limits of the standard British Railways all-steel frame and body. The vehicles now nearing completion at Doncaster. however, will have interior layout, design and equipment based on a special study of future design by a panel of B.T.C. and British Railways experts, with detailed decor commissioned from a design group. These vehicles, one of which will include revolving and reclining seats, anti-sun glass windows, and other features, represent a range of developments from which final selection will be made on the basis of public reaction and practical experience under service conditions.

The first prototype main-line coaches have been completed and consist of one corridor first, and one corridor second built by the Metropolitan-Cammell Carriage & Wagon Co. Ltd.; the prototype restaurant cars were placed in service in July last year.

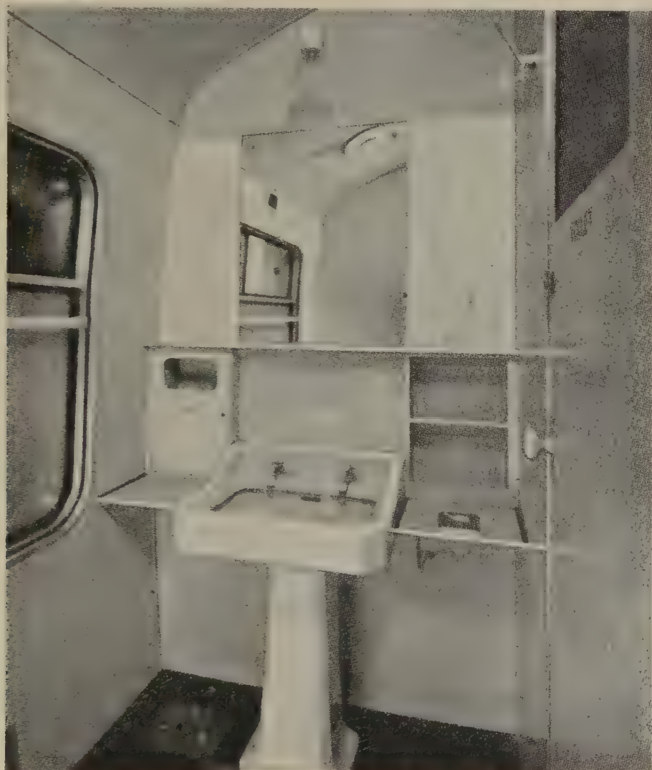
Interior of first class compartment, showing layout and seating.

Basic standard dimensions.

Although the Metropolitan-Cammell Carriage & Wagon Co. Ltd. were given a free hand on producing a design of modern conception, and decor, basic dimensions were to be to British Railways standard, to include bogies, underframes, and body shell, with a maximum width of 9 ft. They were also to be designed to withstand an end loading of 200 t.

Instructions to proceed with the work were received by the builders on December 22, 1955, with delivery within 12 months.

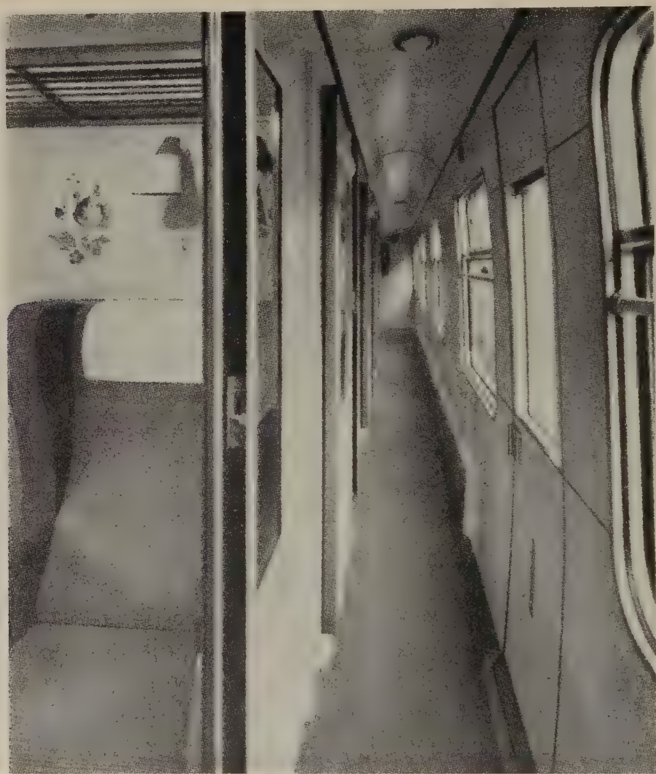
The total number of passengers to be carried was not laid down but Metropolitan-Cammell would have, within the above stipulations, a free hand to put forward their own ideas for seating, lighting, heating and general interior finish and decoration. A number of new ideas have been incorporated all of which are designed to increase the comfort of the passenger. For instance, there are six compartments instead of seven in the first class coach, and seven instead of eight compartments in the second class coach, thus giving increased space in each compartment and more leg room for each passenger. Both shells have been sprayed with Limpet asbestos to deaden noise and increase insulation properties. Double glazed window units have also been incorporated with the same object in view, at the same time helping to avoid condensation.



Ladies powder room, first class coach.

The interior finish is of plastic throughout which will give maximum wear with the minimum amount of maintenance. This type of finish will ensure cleanliness, and mouldings have been kept to the minimum. In the first class coach a special heating arrangement has been fitted to provide a blanket of warm air

between the cold surface of the window and the passenger. This arrangement also acts as a demister. In both coaches, however, there is heating along the corridor, broken only at the central doorway. In the first class coach, individual highback armchair seats have been provided with a new type of upholstery. Each seat also passenger seat in both the first and second class coaches, with contemporary style shades, and a more efficient lighting system has been provided throughout, together with a greater power of light. The luggage racks are of tubular design, and decorative panels in plastic appear above the seats on either side, these being



First class corridor, showing plastic panelling.

has a Terylene head cover. The seats in the second class coach are of all-aluminium construction to give maximum strength with minimum weight. They are fitted with hinged arm rests and a modern type of upholstery, the seat covers being designed for easy removal for cleaning purposes.

One reading lamp is provided for each incorporated in the Formica veneers. In the first class coach two individual collapsible and plastic-topped tables per compartment are provided at the windows for drinks, and so on, whereas in the second class coach a wider fixed shelf than normal has been provided for this purpose.

There are separate lavatories for ladies

and gentlemen and the provision of a special powder room for ladies is an entirely new feature. Decorative panels in plastic appear here as well as in the compartments. There is also increased ventilation in the lavatories ,with special extractor fans. There is a higher ceiling than usual. Another feature is the installation of an electric indicator system at the end of the corridor to indicate when the lavatories are engaged. The following is a list of sub-contractors who supplied materials for the new stock.

Sprayed Limpet asbestos	J. W. Roberts Limited.
Window & ventilator units	Hallan, Sleigh & Cheston Limited.
Double glazing	Pilkington Bros. Limited.
Side door droplights	Becket, Laycock & Watkinson Limited.
Interior plastic panelling	Thomas De la Rue & Co. Limited.
Mural designs and colour scheme	Courtney Jaques.
First class seating	Pel Limited.
First class seating and curtain material	Edinburgh Weavers.
Second class seating material	British Replin Limited.
Seat interior cushions	Dunlop Rubber Co. Limited.
Electric light fittings	A. E. I. Lamp & Lighting Co. Limited.
Toilet fittings	Twyford Limited.
Floor coverings	Linoleum Manufacturing Co. Limited.
First class carpets	T. F. Firth & Sons Limited.
Parcel racks	Birmingham Guild Limited.
Aluminium anodise finish	Anotints Limited.

The tare weights of the first and second class coaches is 35 t 12 cwt. 1 qr. and 34 t 5 cwt. 2 qr. respectively.

[721 .1]

Improved rail pile.

Three unserviceable rails welded bottom to bottom.

(*The Railway Gazette*, February 15, 1957.)

The present short and costly supply of new steel is proving an increasing incentive to use second-hand steel of good quality for many purposes whenever possible. Track-worn rails are available in comparatively large quantities, but more often than not are used where steel of such good quality is not essential. However, their high-strength can be made use of effectively for fabricating such articles as steel piles.

Some 20 or more years ago the engineers of the Southern Pacific Railroad designed a type of pile in which three rails were welded together head to head along their lengths, the webs radiating at angles of 120° from one another. It proved quite satisfactory, but there was some difficulty in the welding and, as other suitable sections of new steel were then comparatively plentiful and cheap, this pile did not become generally popular.

In present stringent circumstances, therefore, it is not surprising that a somewhat similar but improved design of rail pile has been evolved by a firm in the U. S. A. Known as the Foster Rail Pile, it has advantages over its Southern Pacific predecessor, especially in respect of the welding. In it the bottoms and not the heads of the three rails are welded together. The webs and heads project outwards at 120°, providing a symmetrical section modulus round any axis with a heavy concentration of steel in the rail-heads or flanges; the triangular-arranged bottoms can easily be welded. Fabricated in such high-strength steel this section provides a pile that is extremely rigid and exhibits a notable resistance to distortion.

Severe tests.

This was recently demonstrated to a gathering of engineers, contractors and Government officials when three 80-ft. piles fabricated from three different sections of rail were driven to refusal in bed-rock by a single-acting steam hammer rated at 30 000 ft.-lb. per blow. In fact, they were driven to a final penetration of at least 60 blows per in., yet none showed any distortion nor were the heads even marked by the hammer, it is stated. The pile with the lightest section was fabricated with 60-lb. rails rolled in 1882, and on withdrawal was found to be undamaged in any way.

Another severe test with piles composed of 60, 80, and 90-lb. rails consisted of the battering of each 200 times with a 17 500-ft.-lb. blow, their bases resting on a rigid 5-in. anvil plate; there was no visible effect on any of them reported.

Their success is said to be partly accounted for by improved welding techniques, the bottoms of the rails being welded with series of 4-in. long welds spaced at 16-in. centres and a continuous 12-in. weld at each end. For longer piles additional rail lengths can be added as required by butt-welding in the field.

NEW BOOKS AND PUBLICATIONS.

[**656** .2 (73)]

BARRIGER (John Walker). — **Super-Railroads for a dynamic American economy.** — One volume (7 7/8 × 10 1/4 in.) of 92 pages with numerous tables. — 1956, New York, Simmons-Boardman Publishing Corporation, 30 Church Street. (Price : $ 2.—).

Intended to arouse the railway world as well as the great American public and lead them to reflect upon the indispensable modernisation of the railways, the recent book « Super-Railroads » by John W. Barriger, Chairman of the « Pittsburgh & Lake Erie R. R. », has managed to set out in incisive terms a problem which in the United States as in other countries becomes more and more grave every day, so that partial solutions will no longer suffice : namely the adaptation of the railway to the requirements and situation obtaining in the modern world.

The great decline in receipts in the United States in 1954 — $ 1 107 000 000 for the period from the 1st January 1954 to the 30th September 1954 — led the author to investigate the immediate causes, and after carrying his anlysis still further, to formulate those remedies which should enable the railways if not to benefit to the same extent as the general economic activity, at least stop the decline in their general relative importance in the field of transport. The transfer of traffic to other forms of transport has been, in fact, both in its total extent and proportionately, greater than the total national increased demand for transport.

It is a mistake to think, for example, that if a given volume of traffic sufficed for an undertaking to live some years ago, the same volume would now be sufficient to allow it to survive, owing to the increased wages and cost of materials.

But what is more serious, says the author, is that the public seeing the relative decline of the railway and having at the same time a strong inclination to consider it outmoded, has absolutely no idea of what it is losing by not having the use at the present time of the much more efficient tool the railway would have been had if its economic and financial position allowed it to develop to the extent now made possible by technical knowledge.

Making a distinction between large scale transporters (those who carry a large volume with each unit of transport : train, boat) and transporters using smaller units (lorries), the author shows by numerous examples how the costs in the former case (on the average 2 cents per ton-mile) are only a fraction of the latter (about one tenth), but also how the former are much more vulnerable to very slight reductions in the traffic. If in spite of this the progress made by road transport is obvious, this is due, he says, to the railway stock which is no longer in line with requirements, as well as to the technical shortcomings and limitations of the terminal installations at the present time which result in extremely unfortunate delays in delivery. In the long run, the very existence of the railway is at stake in districts where there is a well developed road network unless steps are taken to improve matters.

In the United States, the large scale introduction of Diesel traction has certainly made it possible to improve matters during the last ten years, and to slow down the decline owing to the performances obtained (increased output and availability, high average speeds, much heavier trains — up to 17 000 t — though fewer, reduction of the train staff to one

fifth or less, increased output of the lines which can often be reduced to single track, additional time for mechanised permanent way maintenance work, less stress on bridges, etc.).

But, thinks the author, in the present age of « superhighways » « supermarkets » and other « supers », the railway must become a « super-railroad », if it is to serve its epoch. Far from remaining content with a layout that has remained practically unchanged since 1914, new lines must be made or existing lines rectified, in order to allow the express train to run at an average speed of 100 miles an hour (the top speed being only a little higher than this figure). Gradients must be limited to 0.5 % and the radii of curves must not be less than 1 750 m. Because its straight and level lines are the railways trump cards. Present day equipment makes it possible to construct the necessary embankments and tunnels without undue cost. (The author considers that about seven and a half thousand million dollars would have to be invested under this heading in the United States in order to have about 60 000 km (37 300 miles) of lines answering to this standard). The signalling and telecommunication installations must follow the same pattern, centralised traffic control, cab signals and automatic braking of the trains being essential.

The marshalling yards recently equipped for automation have shown the path to be followed. The great majority of marshalling yards should be dealt with in the same way, thus saving the annual loss of millions of wagon-hours, in fact of wagon-days in the terminal marshalling yards and installations. The stations also need redesigning so that there will be fewer switches and secondary lines, thus allowing of a much greater output. At least five thousand million dollars will be required for this.

At the present time, far more money is spent on maintaining and repairing the rolling stock than in running the trains. The author suggests that standardisation should be carried much further for all the stock and the shops should be completely modernised. At the same time, stock more than twenty years old should be cut down to a very small percentage of the total.

The author is of the opinion that the progress of the railways will continue, as in the past, to be directly linked up with the progress of its traction units. Although the Diesel has already made it possible to carry out sensational modernisation during the last ten years, the « super-railroads » of the future will demand much more. There is no doubt that before 1965, 20 000 000 HP of Diesel locomotives must be built. But the author makes a detailed analysis of electric traction : the cost of the kilowatt-hour produced on Diesel locomitves is 3.5 to 11 cents (average : about 4 cents), whereas the cost of the kilowatt-hour bought from the power stations varies between 0.6 and 1 cent with much greater flexibility. Barriers of an economic nature (high cost of the lines and catenary) must and consequently can be overcome, especially as operating and traffic are much easier with electric traction.

The development of the installed power in the electric power stations will however remain low as a capacity of 750 000 HP will meet the needs of the some 3 million 500 000 HP installed on the present electric locomotives and rakes. The author therefore thinks that between 10 000 and 22 500 miles of the « super-railroads » will be electrified (as compared with the 2 000 miles now electrified).

Going on to the wagons, the worst of which in a rake limits the speed of the train in which it is running, the author thinks it will be necessary to improve them to allow of speeds of 70 miles an hour. Taking into account the increase both of the turn round and the traffic, a stock of some 1 500 000 wagons would suffice in the United States compared with the present 2 000 000. Wagons which

could run at 80 miles an hour, and strong enough to be included in 15 000 t, trains, could be built in series and would only cost five thousand dollars apiece. A sum of five thousand million dollars would be needed for the first purchases (up to 1965).

Finally, the quality of the service of the « super-railroads » would make it possible in most cases to delivery goods the following day over distances of the order of 800 km (500 miles), passengers would be carried more comfortably and quicker (12 h from New York to Chicágo instead of 16 ½), so that the enormous capital investment would be an extremely attractive one — the author details a plan based on twenty thousand million dollars. (The present review obviously cannot go into details about the carefully selected figures, which can be found in the book).

As can be seen, Mr. J W. BARRIGER's book, if it is a cry of alarm, is also a definite proposition for the modernisation and renewal of the railway. He analyses the various aspects of the problem and makes many suggestions. Perhaps the point that has not been gone into so thoroughly is that of the terminal installations.

P. SCH.

[**656**]

LOCHNER (N.) and WILTS (J.). — **Wachstum und Wettbewerb im Nordatlantischen Personenverkehr.** — *(Progress and competition in North Atlantic passenger traffic).* — Researches of the Institute of Transport of Munster University. Volume II. — One volume (6 1/4 × 9 1/2 in.) of 180 pages with numerous graphs and tables. — 1956, Göttingen, Vandenhoeck & Ruprecht (Price : 26 DM)

The object of this volume is to study the development of passenger transport across the North Atlantic and competition between the airways and maritime lines.

It consists of two books. One, by Norbert LOCHNER, deals more particularly with air transport; the other, written by Jelke WILTS, is devoted to the economic problems confronting the maritime companies.

In the first book, the author examines the circumstances in which air transport across the North Atlantic has developed. The capital invested, the cost factors, the evolution of laws covering air travel, the influence of the available traffic and that carried, and the incidence of special rates are amongst the questions discussed on the bases of material collected from reliable sources.

The first part of the second book deals with the competition between aviation and the sea routes. The author goes into details about the considerations which influence a passenger's choice of one or the other.

The second part gives an analysis of the cost of maritime transport and stresses the effects of variations in the traffic obtained.

In the third part, the author examines the economic possibilities of fast transatlantic services, based on data concerning speeds, powers and constructional costs, and discusses the question of the most economical types of ships in view of air competition.

This work is of the greatest interest, on the one hand because of the points of view put forward, and on the other by the quantity of information of an economic nature that has been collected together. This information, at least the main points, are shown in instructive diagrams appended to the text.

E. M.

[**385** (09 (66)]

EMERSON (R.B.), C.I.E., O.B.E., M. Inst. T., General Manager, Nigerian Government Railway, **Nigeria. — Annual Report on the Government Railway for the financial year 1954-1955.** — One volume (8 1/4 × 13 3/8 in.) of 92 pages with tables, graphs, illustrations and maps.

The Nigerian Railway operates 1 903 miles of line, of which 1 770 miles are 3 ft. 6 in. gauge and 133 miles 2 ft. 6 in. gauge. The railway serves two ports on the Atlantic.

Steam locomotives are used for traction, but Diesel-electric locomotives were introduced during the year, and have been favourably received on a section where there is a water shortage.

Owing to the new organisation which has placed the railway under the authority of a group known as the Nigerian Railway Corporation since the 1st October 1955, this financial year is the last one for the old State Railway undertaking.

The report notes with satifaction that during it last complete year, the State Railway carried a greater amount of traffic, earned larger receipts and obtained a better net output that during any previous year. These results are due to the freight traffic, particularly the export traffic, although imports also have been encouraged by the development of the country. Internal traffic is constantly increasing.

The initial chapter recording these essential factors also describes the other outstanding features of the year. The prosperity of the country has justified the preparation of a five year plan covering rolling stock and extensions to the lines.

In the following chapters the report gives details about the services and transport, the stock, the permanent way and fixed installations, the stores and the staff.

Numerous statistical tables show the material position and functioning of the undertaking. It can be seen from one diagram that for many years the receipts and costs have continuously increased, with an operating coefficient considerably below the unit.

E. M.

[**313** : **656** (4)]

Annual Bulletin of European transport statistics 1955. — Published by the *European Economic Commission, Transport Division* of the United Nations, Geneva. — One volume (8 1/4 × 11 in.) of 102 pages, with graphs and maps. — 1956, Genève, Office Européen des Nations Unies, Palais des Nations. (Price : 5 Swiss francs).

These statistics relate to European overland transport, by rail, road and waterways.

There are four chapters giving the data collected respectively for : the traffic, the systems, the rolling stock, the use of both fixed and mobile equipment.

The volume consists of the text on the one hand and general tables in addition to the text, as well as tables and graphs inserted in the text.

In the light of the figures collected, chapter I studies the structure and evolution of traffic for the three categories of transport. Comparisons are made between different countries both as regards passenger traffic and freight traffic.

Chapter II gives the comparative situa-

tion of the development of the different undertakings. It is interesting to see that in many countries new railway lines have been built and other lines have been converted to double track.

Electrification has made appreciable progress and vast electrification programmes are being studied.

Chapter III confirms that steam traction is on the wane, though some new steam locomotives have been bought in several countries. In the case of passenger transport, railcars and rail motor coaches continue to gain ground.

On the roads, there is an increase above all in the number of private cars.

In chapter IV, the statistics for the railways show a better user of the traction units and rolling stock. Nearly everywhere the traffic per kilometre of line has greatly increased.

In the case of the roads, figures concerning user are very few. In the case of the waterways, although the user is not very intensive, there is very great activity on certain specially favoured routes.

E. M.

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[016. 385 (02]

I. — BOOKS.

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La régulation automatique en chauffage et conditionnement d'air. Traduit de l'anglais par J. GENEVAY.

Paris, Eyrolles, éditeur. Un volume relié (16 × 25 cm) de 388 pages, avec 291 figures. (Prix : 3 700 fr. fr.)

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Paris, Dunod, éditeur. Un volume (16 × 25 cm) de XII-296 pages, avec 170 figures. (Prix : broché, 1 960 fr. fr.)

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[016. 385 (02]

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